

NASA Technical Memorandum 106310

1N-07
203602
51P

Transient Ejector Analysis (TEA) Code User's Guide

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December 1993

(NASA-TM-106310) TRANSIENT EJECTOR
ANALYSIS (TEA) CODE USER'S GUIDE
(NASA) 51 p

N94-23466

Unclass



G3/07 0203602

TRANSIENT EJECTOR ANALYSIS (TEA) CODE USER'S GUIDE

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SUMMARY

A FORTRAN computer program for the semianalytic prediction of unsteady thrust augmenting ejector performance has been developed, based on a theoretical analysis for ejectors. That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region. In particular, the inlet and diffuser analyses are simplified by a quasi-steady-analysis, justified by the assumption that pressure is the forcing function in those regions. Only the mixing region is assumed to be dominated by viscous effects.

The present work provides an overview of the code structure, a description of the required input and output data file formats, and the results for a test case. Since there are limitations to the code for applications outside the bounds of the test case, the user should consider TEA as a research code (not as a production code), designed specifically as an implementation of the proposed ejector theory. Program error flags are discussed, and some diagnostic routines are presented.

CODE OVERVIEW

TEA is a FORTRAN computer program (TEA.FOR), designed for batch execution, which reads an input file (TEA.DAT) to obtain the necessary program data (ejector geometry, primary nozzle conditions, free-stream conditions), solution control options, and file output requests for print and plot files (TEA.OUT and TEA.PLT, respectively). An overview of the TEA.FOR program follows; the required TEA.DAT input file structure is the subject of the next section.

The main program simply serves to open the necessary I/O files and instructs the processing of input data, after which the governing equations are solved.¹

A total of three subroutines are contained in the TEA.FOR file;² they are

DIP - Data Input Processor
MEC - Main Execution Control
SPC - Single Point Calculation

¹ The solution procedure can be influenced by input file specifications.

² Appendix B provides a complete listing of the TEA.FOR file. Some idea of complexity is given by code length: the code is 731 lines long, divided into 21 lines for the main program, 164 for the DIP, 57 for the MEC, and 569 for the SPC. Programming style leans toward clarity rather than conciseness. The development platform for this code was a VAX 8800; the code has not been tested on other platforms.

Figure 1 illustrates that the SPC routine is called by the MEC routine. Although the primary purpose of this document is to provide instructions for preparation of the TEA.DAT file (read by the DIP), some brief remarks on each program module are helpful in interpreting the overall program structure.

Module Descriptions

Data input processor. — The data input processor (DIP) is designed to obtain baseline ejector engineering information, free-stream properties, solution control options, and printout and plot control parameters from the input data file and place this information in COMMON blocks; the use of COMMON blocks reduces (or eliminates) the need for READ statements in other program subroutines.

Input data is read from TEA.DAT according to a macro command sequence. The DIP echoes essential program data (specified and default) so the user can conveniently identify incomplete or incorrect input data. In the interest of clarity, the DIP routine was not written as compactly as possible; this is an overriding perspective throughout the code. For ease of use, all data has a free-format structure — the user need only demarcate values with a comma, rather than be concerned with the customary Hollerith and data format (e.g., 2F12.3).

Main execution control. — The main execution control (MEC) routine provides the basic service of feeding the single point calculation (SPC) subroutine argument list with the information needed to compute ejector thrust at a specified point in time. Although it may appear the MEC is a trivial routine to include, it facilitates development of an SPC that is void of I/O for the time-dependent primary flow conditions.

A previously mentioned aspect of the DIP and MEC subroutine structure is the absence of subroutine calls — all information is transmitted through COMMON blocks. While this may not be the most effective programming practice,³ it is an approach that met the simulation specifications at the time the code was under development.

Single point computation. — The single point computation (SPC) subroutine is the focal point of the TEA program and provides the code implementation of the transient ejector theory given by Drummond (ref. 1). Execution of the SPC routine is controlled by the MEC, since the SPC is structured to be a “drop-in” module for integration in, for instance, an aircraft engine simulation. The SPC is the largest program subroutine, consuming almost two-thirds of the overall TEA code (see lines 243-731 of the listing in Appendix B).

Information for the SPC routine is transmitted primarily through COMMON blocks. This influence on the TEA computer program was the result of a requirement that the SPC argument list include only the primary flow conditions (m , T_{1P0} , P_{1P}) at a given time t , and return thrust and augmentation ratio (T , ϕ) for a real-time component-level-model engine simulation.⁴ This requirement is clearly simulation specific, but does provide module parameter inputs consistent with information

³ The COMMON block chalkboard approach to programming can make program error tracking during diagnostics a difficult process.

⁴ As discussed by Drummond (ref. 1), the motivating factor behind the development of the transient ejector theory was the need to develop a high-fidelity propulsion system simulation for the Advanced Short Take-Off and Landing (ASTOVL) development program.

typically available to an engine simulation code.⁵ Although alternate simulation requirements may result in the need for a different SPC argument list, the modular code structure remains quite convenient.

Comment cards in the SPC routine mark out blocks of calculations corresponding with calculation steps in the theory; an outline of the SPC solution procedure is shown in figure 2.

Within the SPC module, there exists a decision branch between quasi-steady and transient flow calculations, based on the value of an execution mode switch, MODE, in the SPC argument list; this points to an important aspect of an ejector mixing region analysis. Since it is expected that transient ejector performance predictions are kicked-off from an assigned initial condition (there can be more than one initial condition of interest), there is a need for a built-in initialization routine for the field variables. A quasi-steady solution to the governing equations is associated with a value of MODE=0; such a solution does not invoke time derivatives in the analysis and provides, by default, a series of steady-state flow computations. When MODE=1, a transient solution is invoked which reflects the implementation of the proposed transient ejector theory.

System of units. — Few applications in engineering analysis appear to be exempt from the need to clarify the system of units involved in calculations. Typically, confusion extends from translating back and forth between force, mass, and pressure; the usual remark is that a consistent system of units must be used in analysis, and that certainly is the case here. In the present work, the Engineering English system of units is used.

With the backdrop that the current work represents a research code, the use of the Engineering English system was appropriate for the system simulation during the code development period (in which this code was ultimately intended to be compatible with a propulsion system simulation that used a similar unit system; the Metric system was not appropriate for the simulation application).

The Engineering English system is based on four fundamental units for length, force, time, and mass. Units of length are in feet (ft), units of time are in seconds (s), units of force are in pounds-force (lb_f), and units of mass are in pounds-mass (lb_m). Compatibility of units is provided by the introduction of the gravitational constant $g_c = 32.174$ into Newton's law (g_c is numerically, but not dimensionally equal to the gravitational constant). Although the work of Drummond (ref. 1) provides extensive examples on the appropriate units for each variable involved in the analysis, the following summary is relevant to input file preparation:

| Description | Mnemonic | Value = Units |
|---------------------|----------|-----------------------|
| Temperature | T | = °R |
| Pressure | P | = lb_f/ft^2 |
| Velocity | V | = ft/s |
| Density | RHO | = lb_m/ft^3 |
| Mass flowrate | MDOT | = lb_m/s |
| Specific heat ratio | GAMMA | 1.4 = non-dim |
| Gas constant | RBAR | 1715.66 = ft^2/s^2R |
| Angle of attack | ALPHA | = degrees |

⁵This leads to certain calculations that normal ejector codes would not have a requirement for, or the use of (e.g., a total pressure versus static pressure specification at the secondary inlet).

In principle, there is nothing to prevent the user from using, say, the Absolute MKS system of units (g_c has a value of unity) since equations involving the value of g_c do so symbolically. Illustrations of this are shown in lines 118 and 122 of the SPC routine — g_c is set at the top of the SPC module (line 67) and could be reassigned as desired.

INPUT DATA FILE PREPARATION

Typical File Structure

Data processing for the TEA.FOR program involves extensive use of macro commands; macros are keywords placed in the input file which permit a flexible input data file structure. Appendix A provides an example⁶ input file structure.

Although the macro command structure can be perceived as a somewhat clumsy programming practice, the result is a very lucid input file structure. Another benefit to the macro approach is that the blocks of data are not required to be placed in any particular order, and in some cases they need not appear at all (as long as the program defaults are acceptable to the user). A subtle feature of the macro command approach is that the program will ignore any lines that do not begin with a recognized keyword — as such, the user can include as many descriptive comment cards as desired at the top of the file for a full description of the case study at hand.⁷

Macro Commands and Options

Within the data input processor (DIP), solution instructions, data input, and data output specifications are read from the TEA.DAT file through a macro command structure. As mentioned previously, COMMON statements are extensively used as placeholders in memory to shuttle data from one routine to another. Except for the SPC, none of the subroutines have argument lists since the necessary information is provided by the COMMON statements. For this type of data transfer, sub-program macros are very useful.

Data to be processed within the DIP block is subdivided according to a logical characterization of the data to be handled. Currently, eight keywords are used in the subdivision of data:

| | |
|-----------------|--|
| 'BACK' PRESSURE | Back pressure specification for ejector discharge (optional) |
| 'CASE' | Case banner for printed output (optional) |
| 'COEF' FICIENT | Empirical coefficients for mixing and entrainment |
| 'DISP' LAY | Display control for printed and plotted output (optional) |
| 'FREE' STREAM | Free-stream fluid properties |
| 'GEOM' ETRY | Geometry of the ejector |
| 'PRIM' ARY | Primary nozzle discharge conditions |
| 'STOP' | Stop command for data input processing (optional) |

⁶ This file corresponds with the test case to be discussed later; for now, however, it is the file structure rather than the numbers themselves that are of interest.

⁷ After several weeks pass, it is easy to forget why a particular case was of interest.

Quotes around the first four letters of each keyword are used to indicate the minimum portion of the word to be included for data file preparation. Only four of the eight data blocks are essential to include in the input file; optional sets are marked accordingly. Except for STOP, which (if used) must be the last keyword encountered in the DIP data block, the keywords and associated data can occur in any sequence desired. Descriptions of the input parameters associated with each macro command are given below (in alphabetical order).

BACK: Ejector back-pressure (optional). — Aircraft installation aerodynamics often dictate that the back pressure of an installed ejector may be different than atmospheric; to accommodate this, the BACK block allows the prescription of a nonatmospheric exit pressure.

| Line | Variable | Description |
|------|----------|---|
| 1 | 'BACK' | Keyword for back pressure input block |
| 2 | 'PBACK' | Value for ejector back pressure [Default: PBACK=PINF] |

This data block is optional if the back pressure is equal to that of the ambient since the program default is to assign the backpressure to the value of the free-stream static pressure (as specified and discussed later in the FREE stream block). PBACK has units of lb_f/ft^2 .

CASE: Banner for printed output (optional). — The descriptive banner is the header for printed output. This data block is composed of two lines:

| Line | Variable | Description |
|------|----------|--|
| 1 | 'CASE' | Keyword for banner input block |
| 2 | 'RUNID' | Banner for printed output [Default: RUNID='TEA'] |

The CASE block is optional; the program provides a default banner of TEA if this data block is omitted.

COEF: Coefficients for solution type, mixing, kinetic energy entrainment. — As discussed in the work of Drummond (refs.1 and 2) the ejector theory implemented in this work employs two empirical constants, the flow mixing effectiveness, BETA (β), and the coefficient for the kinetic energy transfer function, CSIGMA (C_s).

| Line | Variable | Description |
|------|---------------------------------|---|
| 1 | 'COEF' | Keyword for coefficient data block |
| 2 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 3 | 'ITYPE', 'BETA', 'CSIGMA' | Type of solution desired (0 = Steady; 1 = Transient) Mixing effectiveness factor ($1.0 < \text{BETA} < 2.0$) Kinetic energy coefficient ($0.0 < \text{CSIGMA} < 1.0$) |

In the interest of making direct comparisons between quasi-steady and full transient flows, this block introduces the option of enforcing a quasi-steady flow assumption. What essentially happens is that the steady-flow initialization routine is invoked for all point calculations emanating from the MEC. The default integer has a value of ITYPE=1 and marks the full transient flow as the execution mode; a value of 0 eliminates time derivatives to provide the quasi-steady option (ITYPE sets the value of the MODE parameter discussed previously in the SPC overview).

DISP: Printout of intermediate computations (optional). — For detailed investigations of transient performance calculation results, three parameters can be set to control printed output and plot file information.

| Line | Variable | Description |
|------|----------------------------------|--|
| 1 | 'DISP' | Keyword for display data block |
| 2 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 3 | 'ICHECK', 'INDEX', 'IPLOT' | Integer for printed calculation output [Default: ICHECK=100] Indexing for printout loops [Default: INDEX=1] Index for plotfile data [Default: IPLOT=0] |

Values of ICHECK can range between 0 and 1000, where 0 provides no printed output at all, 50 provides only a print summary from the DIP and MEC routines, and a value of 100 (the default) provides detailed listing of SPC results as each time step calculation is completed.⁸ For diagnostic applications, ICHECK = 500 provides detailed velocity initialization data, and at ICHECK = 1000, self-similar profiles and secondary velocities are printed for every iteration within each time step. The INDEX parameter is useful if the program has operated on, for instance, 500 primary nozzle states, and it is desired to only printout every 10th computed result; INDEX must have a value greater than or equal to 1. The IPLOT parameter dictates whether a plot file is to be created, and the intervals at which data is written to the plot file. For the default value of IPLOT=0, no data is stored in the TEA .PLT file. For IPLOT = 1, primary flowrate, thrust, and thrust augmentation are stored at each time interval; for values of IPLOT = N, every Nth data point is stored (much like the INDEX function).

Plot file output parameters are controlled by the WRITE statement at lines 231-235 in the code. At present, only parameters passed through the SPC argument list are amenable to place in the plot file; other parameters could be used if the appropriate WRITE statements were written to replace the existing segment of code.

FREE: Free-stream fluid properties (optional). — Characteristic (free-stream) flow properties and thermodynamic data are contained in the FREE stream data block.

| Line | Variable | Description |
|------|---|--|
| 1 | 'FREE' | Keyword for free-stream data block |
| 2 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 3 | 'TINF', 'PINF', 'GAMMA', 'RBAR', 'UINF', 'ALPHA' | Free-stream static temperature [= 530°R; default value] Free-stream static pressure [= 2116.8 lb _f /ft ²] Specific heat ratio [= 1.4 nondim] Universal gas constant [= 1715.66 ft ² /s ² R] Free-stream velocity [= 0.0 ft/s] Angle of attack [= 90.0 deg] |

To simplify the implementation of the ejector theory, the primary and secondary ejector streams are assumed to have the same gas composition (this is not a restriction of the theory).

⁸ The rationale for the ICHECK values of 0, 50, 100 (instead of 1, 2, 3) extends from the prototype code effort to interface with the airframe simulation.

GEOM: Ejector geometric characteristics. — Geometric approximations for the ejector are contained in the GEOM data block. All numeric data must be preceded by a title. Data is expected in the following order:

| Line | Variable | Description |
|------|---------------------|--|
| 1 | 'GEOM' | Keyword geometric data input block |
| 2 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 3 | 'X0,Y0' | Inlet (station 0) x- and y-dimensions |
| 4 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 5 | 'X1,Y1, NX1,NY1' | Primary nozzle (Stn 1) x- and y-dimensions x-section Number of nozzles in the x,y- directions |
| 6 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 7 | 'X2,Y2' | Secondary flow (station 2) x- and y-dimensions |
| 8 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 9 | 'X3,Y3' | Mixing region (station 3) x- and y-dimensions |
| 10 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 11 | 'X4,Y4' | Diffuser exit (station 4) x- and y-dimensions |
| 12 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 13 | 'Z1,NZ1' | Total mixing region length and number of finite volumes |

Figure 3 illustrates the expected geometric layout of the ejector; specific data was shown previously in Appendix A.

PRIM: Primary nozzle discharge conditions. — This block specifies the primary nozzle discharge velocities and thermodynamic properties.

| Line | Variable | Description |
|------|----------|--|
| 1 | 'PRIM' | Keyword for primary nozzle data block |
| 2 | 'TYPE' | Keyword for nature of data to follow: 'SPEC' -> Data specified for every t 'STEP' -> Step function specification |

If TYPE = 'SPEC', then the following input data sequence is expected:

| Line | Variable | Description |
|--------|--|---|
| 3 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 4,...N | 'T(I), DMPDT(I), T1P0(I), P1P(I)' | Time stamp Primary flowrate Stagnation temperature Static pressure |
| N+1 | 0 | Number(s) or character(s) to trigger end of record |

Note that there are four data values on each of the 4,...N lines to simulate the primary nozzle conditions as a function of time. The N+1 reading must be a number or letter format that will terminate input by triggering an error in the READ loop (a simple single value of '0' works fine; see Appendix A).

If TYPE = 'STEP', then the following input data sequence is expected:

| Line | Variable | Description |
|------|-----------|---|
| 3 | 'TITLE' | Descriptive comment for variable list |
| 4 | T(1) | Starting time |
| | DMPDT(1) | Starting primary flowrate |
| | T1P0(1) | Starting stagnation temperature |
| | P1P(1) | Starting static pressure |
| 5 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 6 | 'Z1TIME' | Time at which step-change occurs |
| | 'Z1DMDT' | New primary flowrate |
| | 'Z1T1P0' | New stagnation temperature |
| | 'Z1P1P' | New static pressure |
| 7 | 'TITLE' | Comment line with descriptive titles for variables on next line |
| 8 | 'TSTEP,N' | Time-step size and number of time steps to take |

STOP Statement (optional). — The end of input data is marked by the presence of the QUIT card.

| Line | Variable | Description |
|------|----------|-----------------------------|
| 1 | 'STOP' | Keyword to exit DIP routine |

ILLUSTRATIVE CASE

Background

Research on design methodologies for integrated aircraft and flight control systems requires accurate subsystem component simulations. In principle, these simulations must mimic steady-state and transient component effects. Of particular interest in recent years is the development of real-time simulations for short take-off vertical landing (STOVL) aircraft.⁹ The thrust augmenting ejector shown in figure 4 is considered a potentially valuable propulsion subsystem element for the powered-lift aspect of STOVL aircraft.

Steady-flow ejector performance predictions are typically the centerpiece of an ejector design cycle, and transient flow behavior is most often described through a quasi-steady flow approximation. The latter essentially assumes away the transient behavior issue since the conjecture is the ejector will instantaneously provide whatever thrust is demanded.

To establish the validity of the quasi-steady flow assumption, one must be able to quantify the elapsed time for the ejector to adapt to a new thrust level, and establish that the ejector delay is less than the control system update period. In air-breathing propulsion systems, this assessment can take the form of a comparison between the ejector frequency response and that of the propulsion control system; see figure 5. The purpose of the TEA program is to assist in the assessment of the ejector response rate; the specific case study used to examine the STOVL response rate is presented next.

⁹ For more extensive details on the simulation of interest, see Drummond (ref. 2), or Drummond and Ouzts (ref. 5).

Characteristic Test Case

In the absence of appropriate¹⁰ data from transient flow ejector experiments or from advanced time-dependent CFD calculations, verification that the proposed ejector analysis can provide reasonable thrust predictions must be left to engineering judgement. Because of this, a familiar forcing function must be used. In the present work, the system response to a step-function input is not only a characteristic transient case study, but the scenario is coincident with typical STOVL ejector application. For demonstration purposes the ejector system response to a step-change in primary nozzle flowrate from 18.7 to 21.85 lb_m/sec is chosen because (1) experimental steady-state data at each of these operating points is available, and (2) the 17 percent change in primary flowrate is beyond the small-perturbation range; this exercises the system nonlinearities. Two versions of the TEA.DAT input file were prepared¹¹ for this case study and are given in Appendix C.

Geometric approximations for the ejector inlet, mixing region, and diffuser are presented in table I note the 3-D to 2-D conversion required for the primary nozzle area. This conversion in nozzle geometry is required so that the input data will be consistent with the mathematical formulation of the ejector mixing layer.

Results

For the mixing region, a finite-volume length of 0.18 ft and a characteristic mixing region velocity of 500 ft/s, the characteristic time step for computations is approximately 0.4 ms. To avoid infringing on this stability limit a computational time step of 0.1 ms was chosen; 100 time steps provided the necessary interval for examination of the step-function test case.

A detailed listing of the program printout is given in Appendix D, though the results for each of the 100 time steps are not shown (for brevity).

The empirical coefficient in the transient analysis (required for calibration of the primary-to-secondary kinetic energy exchange mechanism), was selected to match the asymptotic thrust prediction with the quasi-steady value at the new set point. Figure 6 illustrates the predicted ejector thrust profile for a coefficient C_e of approximately 0.25. It appears the 2 millisecond residence time of the flow (elapsed time for the primary nozzle flow to reach the diffuser exit plane) is slightly less than the 3 millisecond interval for the thrust to reach a new maximum. Oscillations in thrust after that point appear to settle out in about 5 milliseconds.

An (initially) unexpected feature of the thrust profile is the dip in thrust immediately following the step-change in primary nozzle efflux. Examination of the field variable profiles reveals this is not a numerical problem, but that the increase in static pressure associated with the instantaneous change in driving flow temporarily impedes the secondary flow. After a short period, the secondary flow kinetic energy builds to overcome this effect and then continues in the intuitively expected manner.

¹⁰ A test was conducted by Drummond (ref. 3). specifically to collect transient ejector data, but the forcing function had a characteristic time much greater than the time scale of interest in simulation validation.

¹¹ The file identifier "TEA.DAT" is hard-coded into the program for simplicity in program development. As such, the examples given in Appendix C are titled CASE1.DAT and CASE2.DAT, for which it is assumed the user will rename the case of interest to be TEA.DAT, prior to execution. The user can automate this process through a simple command language script.

Discussion

Steady-state ejector performance is well-known to be highly sensitive to design conditions, so it should come as no surprise that the transient performance prediction task is as much an art as it is a science. Some aspects of the illustrative test case runs are useful to discuss.

Entrainment coefficient variation. — A critical step in the implementation of the transient ejector theory is the identification of the appropriate value of the empirical entrainment coefficient C_e . For a known ejector step-function response, the desired C_e value is the one that provides a match between the predicted asymptote and the known thrust at the second state. As an example, thrust predictions for various C_e values are shown in figure 8; this chart illustrates the idea that the TEA code was not designed to provide the optimal prediction of steady-state ejector performance¹² — rather, that the code focuses on analysis of transient flow characteristics. (Figure 7 differs slightly from figure 6 in thrust prediction due to a slight modification in the implementation of the theory; figure 7 is the more recent result).

Back pressure effects. — It is possible for several physical reasons that the ejector backpressure will differ from the (upstream) ambient as, for instance, in the case of installation effects or curved mixing regions (asymmetric mixing region). To this end, a performance feature to explore is backpressure limits. The principal goal of increasing the backpressure for any parametric investigation is to establish the threshold at which the mixing region discharge energy is inadequate to overcome the back pressure — in that situation the program notifies the user that a fatal error has occurred (see Appendix A). For the illustrative test case, the backpressure cannot exceed 5 percent over ambient. Error codes are discussed further in the ERROR CODES AND EXECUTION PROBLEMS section.

Performance sensitivity to nozzle geometry. — Ejector performance is very sensitive to ejector geometry. In particular, performance is most readily influenced by the primary nozzle discharge area. For the baseline case, a 20-percent increase in the primary nozzle area yields a 14-percent decrease in primary nozzle discharge velocity, but a 20-percent decrease in the primary nozzle area causes some difficulty in initialization of the program. As illustrated in Appendix A, the initialization difficulty is presented to the user through an error message for a negative entrained velocity. However, during the initialization process, a simple fix is to reset the entrained kinetic energy to a small positive number. This patch seems to work well in the few cases it has been invoked.

A point to be made here is that the ejector transient flow solution involves a highly complex solution logic, and that to encounter an error is not so much a reflection that the input data is incorrect, but that an idiosyncrasy with the solution method may have been encountered.

The discussion in the next section suggests that previous problems encountered with execution have been fixed by altering input data values. Recommendations for algorithm changes or improvements to the theory are outside the scope of this work.

¹² But a sample routine is included to initialize the transient flow calculation procedure.

ERROR CODES AND EXECUTION PROBLEMS

Error Codes

At several points in the previous discussion, it has been noted that program execution may terminate under certain conditions. Five types of errors are currently flagged by the computer; although one could easily inspect the code and potentially identify many more diagnostic flags, those included presently extend from execution experiences with the test case described earlier. Error codes, the current flag location (given by the SPC line number), and a brief description of the problem are given below:

| Error code | SPC line number | Description of problem |
|------------|-----------------|---|
| 001 | 272 | Imaginary value ($B^2 - 4AC < 0$ in the quadratic equation) has been computed for the centerline velocity during initialization of the field variables. If ICHECK has been set to 500, then the XCHECK2 routine will assist in the diagnostics by printing a listing of the variables related to the calculation. |
| 002 | 416 | A negative value for the nominal velocity V^* has been computed (V^* is equal to the entrained velocity V_e cubed). In this case, rates of change in KE have diminished entrainment rates to unrealistically low (negative) levels. The XCHECK3 routine is automatically invoked as a first pass at fixing the problem. (This was discussed in the test case description; see Performance Sensitivity to Nozzle Geometry). |
| 003 | 448 | Unrealistic value for density, the value is less than zero. |
| 004 | 449 | Unrealistic value for density, the value is greater than one. |
| 005 | 452 | Unrealistic value for temperature, the value is less than zero. |
| 006 | 466 | Stagnation pressure at station 4 is less than the static pressure; this results in an unrealistic discharge exit velocity. Either the ejector back pressure is too high or the inlet Mach number is too low. |

These problems are generally symptomatic of the divergence of the transient solution.

Execution Problems

Unrealistic or divergent transient flow solutions may be the result of one of the following:

- (1) An incorrect starting solution (check input data file),
- (2) Too large a time step (modify the input data time history), or
- (3) An inappropriate expression for the function for exchange of kinetic energy between the primary and secondary fluid streams.

The last item is an important one since the entrainment function relies heavily on the assigned value of CSIGMA (see line 185 in SPC). More details on this function and its origin are described in Drummond (refs. 2 and 4).

Optional Debug Routines

Appendix B includes four routines that may be useful for printout of intermediate information during the debugging process. These routines are invoked through INCLUDE statements (to simplify their omission or modification, if desired); typically, these diagnostic routines are unnecessary if the program executes without error.

| Routine name | SPC line number | Description |
|--------------|-----------------|--|
| XCHECK1 | 203 | Printout of self-similar profile coefficient values |
| XCHECK2 | 273 | Printout of data involved in the centerline velocity calculation; used in conjunction with SPC error code number 1. |
| XCHECK3 | 417 | Corrective procedure for negative V^* result; used in conjunction with SPC error code number 2. |
| XCHECK4 | 494 | Entrained velocity error and discharge mass error printouts, used to monitor convergence of a solution at a given time step. |

CONCLUSION

Understanding and quantifying ejector fluid-dynamic characteristics is central to design decisions involved in propulsion system applications. The present work provides instructions for a FORTRAN computer program implementation of a semianalytic prediction of unsteady thrust augmenting ejector performance developed by Drummond (ref. 1). That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region.

An overview of the code structure, a description of the required input and output data file formats, and the results for a test case were presented. It is emphasized that there are limitations to the code for applications outside the bounds of the test case, so the user should consider TEA as a research code designed specifically as a test of the proposed ejector theory. For program applications outside the test case bounds, some error flags and diagnostic routines are presented and discussed.

APPENDIX A - CODE SAMPLES

TEA.DAT: SAMPLE

```
C-----CASE1.DAT---
C
C Case study input file for TEA.FOR transient ejector analysis
C routine. Here a single step function is prescribed that
C corresponds with one of the DeHaviland/PLF tests run in June 1987.
C This file assumes that the default BACK and DISP parameters in the TEA.FOR
C source code are appropriate.
C
C-----
```

CASE banner.

Test #2, Step change in primary flow for 87 DHC ejector design.

GEOMetric approximation for the ejector.

```
XO      YO
0009.36000, 0001.25000
X1      Y1      NX1  NY1
0000.10801, 0000.10801, 00012, 00003
X2      Y2
0000.78000, 0000.34700
X3      Y3
0009.36000, 0001.04100
X4      Y4
0009.36000, 0001.87500
Z1      NZ
0000.90000, 00005
```

COEFFicients for solution execution.

```
1TYPE      BETA      CSIGMA
00001,      0001.0550, 0000.30000
```

FREE stream fluid conditions.

```
TINF      PINF      GAMMA      RBAR      UNIF      ALPHA
0542.80000, 2067.84000, 0001.40000, 1714.54130, 0000.00000, 0090.00000
```

PRIMary nozzle discharge conditions.

SPECify states at each time step.

```
T      MDOT1P      T1P0      P1P
0000.00010, 0018.70000, 0769.70000, 2219.78000
0000.00020, 0018.70000, 0769.70000, 2219.78000
0000.00030, 0018.70000, 0769.70000, 2219.78000
0000.00040, 0018.70000, 0769.70000, 2219.78000
0000.00050, 0018.70000, 0769.70000, 2219.78000
0000.00060, 0021.85000, 0760.60000, 2250.92000
0000.00070, 0021.85000, 0760.60000, 2250.92000
0000.00080, 0021.85000, 0760.60000, 2250.92000
```

0

```
C-----
```

APPENDIX A - CODE SAMPLES

ARIEL\$ RUN TEA

```

$$$ TEA FATAL ERROR # 6, $$$
%MTH-F-SQUROONEG, square root of negative value
user PC 000242C1
%TRACE-F-TRACEBACK, symbolic stack dump follows
module name      routine name      line

SPC              SPC              396
MEC              MEC              38
TEA              TEA              16
ARIEL$

```

ARIEL\$ RUN TEA

\$\$\$ TEA FATAL ERROR # 2, \$\$\$

*** ERROR DURING CALCULATIONS FOR T = 0.00040

```

DKE      = 976309.563
DKEOLD   = 2096179.500
SIGMA    = 71.929
PLOSS    = 11389.766
ENERGY1S = 1076481.875
CHANGE   = -1119870.000
VSTAR    = -1261377.625

```

*** PROCEED W/ CHANGE = -0.999ENERGY1S

*** NEW VSTAR IS = 31295.961

FORTRAN STOP
ARIEL\$

APPENDIX B - TEA PROGRAM LISTING

```

00001 C TEA.FOR: Transient Ejector Analysis - Ver.2.1 15-AUG-91
00002 C=====
00003 C Revised: 15-Feb-93
00004 C Colin K. Drummond
00005 C Propulsion Systems Division
00006 C NASA Lewis Research Center
00007 C Ref: "A Control-Volume Method for Analysis of Unsteady Thrust
00008 C Augmenting Ejector Flows," NASA CR-182203.
00009 C=====
00010 PROGRAM TEA
00011 C
00012 OPEN (UNIT= 5, FILE= 'TEA.DAT',STATUS= 'OLD') ! Input data file
00013 OPEN (UNIT= 6, FILE= 'TEA.OUT',STATUS= 'NEW') ! Output data file
00014 OPEN (UNIT=10, FILE= 'TEA.PLT',STATUS= 'NEW') ! Plot data file
00015 CALL DIP ! Data Input Processor
00016 CALL MEC ! Main Execution Control
00017 CLOSE (UNIT= 5)
00018 CLOSE (UNIT= 6)
00019 CLOSE (UNIT=10)
00020 STOP
00021 END

```

APPENDIX B - TEA PROGRAM LISTING

```

00001 C=====
00002 SUBROUTINE DIP
00003 C
00004 C Data Input Processor (DIP)
00005 C-----
00006 PARAMETER (M=5000)
00007 CHARACTER*80 RUNID
00008 CHARACTER*4 TITLE(20)
00009 DIMENSION T(M),DMPDT(M),T1P0(M),P1P(M)
00010 COMMON /CHECK/ ICHECK,INDEX
00011 COMMON /COEFX/ BETA,CSIGMA
00012 COMMON /ITYPE/ ITYPE
00013 COMMON /PLOTS/ IPLOT
00014 COMMON /LIST1/ X0, Y0,
00015 & X1, Y1, NX1, NY1,
00016 & X2, Y2,
00017 & X3, Y3,
00018 & X4, Y4,
00019 & Z1, NZ1, DZ
00020 COMMON /LIST2/ GAMMA, RBAR, TINF, PINF, PBACK
00021 COMMON /LIST3/ ALPHA, UINF
00022 COMMON /FLOW1/ ISW, N, T, DMPDT, T1P0, P1P
00023 COMMON /FLOW2/ Z1TIME, Z1DMDT, Z1T1P0, Z1P1P, TSTEP
00024 C
00025 C.....DEFAULT DATA
00026 ALPHA = 90.00 ! Angle of attack of aircraft
00027 GAMMA = 1.40 ! Specific heat ratio
00028 ICHECK = 100 ! Print detailed time step output
00029 INDEX = 1 ! Print every I=1 times
00030 IPLOT = 0 ! No plotted output
00031 ITYPE = 1 ! Full transient solution (= 0, steady-state)
00032 PINF = 2067.84 ! Free-stream pressure, lbf/ft2 (14.7 psia)
00033 PBACK = PINF
00034 RBAR = 1714.54 ! Gas constant for AIR, ft2/s2R
00035 RUNID = 'TEA' ! Default RUNID
00036 TINF = 542.80 ! Free-stream temperature, R (70degF)
00037 UINF = 0.0 ! Free-stream velocity, ft/s (stationary ejector)
00038 C
00039 C.....READ INPUT DECK
00040 10 READ (5,'(20A4)',END=200) TITLE
00041 IF (TITLE(1).EQ.'BACK') GO TO 100
00042 IF (TITLE(1).EQ.'CASE') GO TO 110
00043 IF (TITLE(1).EQ.'COEF') GO TO 120
00044 IF (TITLE(1).EQ.'DISP') GO TO 130
00045 IF (TITLE(1).EQ.'FREE') GO TO 140
00046 IF (TITLE(1).EQ.'GEOM') GO TO 150
00047 IF (TITLE(1).EQ.'PRIM') GO TO 160
00048 IF (TITLE(1).EQ.'STOP') GO TO 200
00049 GO TO 10
00050 C
00051 C.....BACK pressure path to read PBACK specification.
00052 C *** Note: This is ONLY needed if PBACK.NE.PINF
00053 100 READ (5,*) PBACK
00054 GO TO 10
00055 C
00056 C.....CASE path to read RUNID banner.
00057 110 READ (5,'(A)') RUNID

```

APPENDIX B - TEA PROGRAM LISTING

```

00058      GO TO 10
00059      C
00060      C.....COEFFicients path to read solution limits and coefficients
00061      120 READ (5,*)
00062      READ (5,*) ITYPE,BETA,CSIGMA
00063      GO TO 10
00064      C
00065      C.....DISPlay path for printout and plotting options.
00066      130 READ (5,*)
00067      READ (5,*) ICHECK,INDEX,IPL0T
00068      GO TO 10
00069      C
00070      C.....FREE stream path to read flow properties.
00071      140 READ (5,*)
00072      READ (5,*) TINF,PINF,GAMMA,RBAR,UNF,ALPHA
00073      PBACK = PINF
00074      GO TO 10
00075      C
00076      C.....GEOMetry path to read baseline ejector geometry.
00077      150 READ (5,*)
00078      READ (5,*) X0,Y0
00079      READ (5,*)
00080      READ (5,*) X1,Y1,NX1,NY1
00081      READ (5,*)
00082      READ (5,*) X2,Y2
00083      READ (5,*)
00084      READ (5,*) X3,Y3
00085      READ (5,*)
00086      READ (5,*) X4,Y4
00087      READ (5,*)
00088      READ (5,*) Z1,NZ1
00089      GO TO 10
00090      C
00091      C.....PRIMary path for specification of primary nozzle state.
00092      160 READ (5, '(20A4)') TITLE
00093      IF(TITLE(1).EQ.'SPEC') GO TO 161
00094      IF(TITLE(1).EQ.'STEP') GO TO 164
00095      C      --- Read step-by-step nozzle condition matrix ---
00096      161 ISW = 0
00097      READ (5,*)
00098      DO 162 I=1,M
00099      READ (5,*,ERR=163) T(I),DMPDT(I),T1P0(I),P1P(I)
00100      162 CONTINUE
00101      163 N = I-1
00102      K = N
00103      GO TO 10
00104      C      --- Read parameters for generating a step function ---
00105      164 ISW = 1
00106      READ (5,*)
00107      READ (5,*) T(1),DMPDT(1),T1P0(1),P1P(1)
00108      READ (5,*) Z1TIME, Z1DMDT, Z1T1P0, Z1P1P
00109      READ (5,*)
00110      READ (5,*) TSTEP,N
00111      K = 1
00112      GO TO 10
00113      C
00114      C.....STOP reading data and print data summary (if ICHECK.GE.50)

```

APPENDIX B - TEA PROGRAM LISTING

```

00115 200 IF (ICHECK.LT.50) GO TO 999
00116     WRITE (6,700) RUNID,ICHECK,X0,Y0,X1,Y1,NX1,NY1,X2,Y2,
00117     &          X3,Y3,X4,Y4,Z1,NZ1,BETA,CSIGMA,TINF,PINF,
00118     &          GAMMA,RBAR,UINF,ALPHA,PBACK
00119     IF (ISW.EQ.0) THEN
00120         WRITE (6,706)
00121         WRITE (6,'((7X,I3,4(2X,F10.5)))')
00122     &          ((I,T(I),DMPDT(I),T1P0(I),P1P(I)),I=1,K)
00123     ENDIF
00124     IF (ISW.EQ.1)
00125     &     WRITE (6,705) T(1),DMPDT(1),T1P0(1),P1P(1),
00126     &          Z1TIME,Z1DMDT,Z1T1P0,Z1P1P,TSTEP
00127     WRITE (6,703) N
00128     IF (ITYPE.EQ.0) WRITE (6,704)
00129     GO TO 999
00130 C.....
00131 700 FORMAT(//,20X,'***** TEA INPUT *****',//3X,A,
00132     &      //,5X,'CHECK PRINT LEVEL IS ',I3,
00133     &      //,5X,'EJECTOR GEOMETRIC CHARACTERISTICS',
00134     &      //,7X,'X0 = ',F10.5,5X,'Y0 = ',F10.5,
00135     &      //,7X,'X1 = ',F10.5,5X,'Y1 = ',F10.5,
00136     &      //,7X,'NX1= ',I5,10X,'NY1= ',I5,
00137     &      //,7X,'X2 = ',F10.5,5X,'Y2 = ',F10.5,
00138     &      //,7X,'X3 = ',F10.5,5X,'Y3 = ',F10.5,
00139     &      //,7X,'X4 = ',F10.5,5X,'Y4 = ',F10.5,
00140     &      //,7X,'Z1 = ',F10.5,5X,'NZ = ',I5,5X,
00141     &      //,5X,'MIXING LOSS CORRECTION FACTOR',
00142     &      //,7X,'BETA = ',F10.5,
00143     &      //,5X,'KINETIC ENERGY MIXING COEFFICIENT',
00144     &      //,7X,'CSIGMA = ',F10.5
00145     &      //,5X,'FREE-STREAM THERMODYNAMIC PROPERTIES',
00146     &      //,7X,'STATIC TEMPERATURE = ',F10.5,' DEG-RANKINE',
00147     &      //,7X,'STATIC PRESSURE = ',F10.5,' LB-F/FT3',
00148     &      //,7X,'SPECIFIC HEAT RATIO = ',F10.5,
00149     &      //,7X,'GAS CONSTANT, AIR = ',F10.5,' FT2/S2-R',
00150     &      //,7X,'FREESTREAM VELOCITY = ',F10.5,' FT/S',
00151     &      //,7X,'ANGLE-OF-ATTACK = ',F10.5,' DEGREES',
00152     &      //,5X,'EJE BACK PRESSURE IS ',F10.5,' LBF/FT2',
00153     &      //,5X,'PRIMARY NOZZLE DATA',/)
00154 703 FORMAT(//5X,'PROGRAM WILL OPERATE ON ',I5,' DATA SETS')
00155 704 FORMAT(//5X,'QUASI-STEADY SOLUTION INVOKED')
00156 705 FORMAT( 7X,'STEP FUNCTION FOR PRIMARY NOZZLE DISCHARGE',
00157     &      //,7X,' T ',4X,' DMPDT',7X,'T1P0 ',5X,' P1P',4X,
00158     &      //,6X,' (sec)',4X,' (lbm/s)',5X,' (degR)',4X,' (lbf/ft2)',
00159     &      //,4(2X,F10.5),/,4(2X,F10.5),//,9X,'TSTEP = ',F10.5)
00160 706 FORMAT(
00161     &7X,'DATA',7X,' T ',4X,' DMPDT',7X,'T1P0 ',5X,' P1P',4X,/,
00162     &7X,'SET#',6X,' (sec)',4X,' (lbm/s)',5X,' (degR)',4X,' (lbf/ft2)')
00163 999 RETURN
00164     END

```

APPENDIX B - TEA PROGRAM LISTING

```

00001 C-----
00002 SUBROUTINE MEC
00003 C
00004 C Main Execution Control (MEC) Routine
00005 C-----
00006 C
00007 PARAMETER (M=5000)
00008 COMMON /CHECK/ ICHECK,L
00009 COMMON /ITYPE/ ITYPE
00010 COMMON /PLOTS/ IPLOT
00011 COMMON /LAST1/ TLAST
00012 COMMON /FLOW1/ ISW, N, T, DMPDT, T1P0, P1P
00013 COMMON /FLOW2/ Z1TIME, Z1DMDT, Z1T1P0, Z1P1P, TSTEP
00014 DIMENSION T(M),DMPDT(M),T1P0(M),P1P(M),THRUST(M),PHI(M)
00015 C
00016 C---LOOP ON SPC ROUTINE FOR SPECIFIED PRIMARY FLOW DRIVER
00017 MODE = 0
00018 TLAST = T(1)
00019 DO 20 I=1,N
00020 IF (I.EQ.1) GO TO 20
00021 MODE = 1
00022 TLAST = T(I-1)
00023 IF (ISW.EQ.1) GO TO 5
00024 TSTEP = T(I)-T(I-1)
00025 GO TO 15
00026 C --- STEP FUNCTION OPERATION ---
00027 5 T(I) = T(I-1) + TSTEP
00028 IF (T(I).GE.Z1TIME) GO TO 6
00029 T1P0(I) = T1P0(1)
00030 P1P(I) = P1P(1)
00031 DMPDT(I) = DMPDT(1)
00032 GO TO 15
00033 6 T1P0(I) = Z1T1P0
00034 P1P(I) = Z1P1P
00035 DMPDT(I) = Z1DMDT
00036 GO TO 15
00037 15 IF (ITYPE.EQ.0) MODE=0
00038 20 CALL SPC(T(I),DMPDT(I),T1P0(I),P1P(I),THRUST(I),PHI(I),MODE)
00039 C
00040 C---PRINT TO TEXT AND PLOT FILES AS REQUESTED
00041 IF (ICHECK.GE.50) THEN
00042 WRITE(6,100)
00043 WRITE(6,'((2X,4(2X,F10.5)))')
00044 & (((T(I)*1000.0),DMPDT(I),THRUST(I),PHI(I)),I=1,N,L)
00045 ENDIF
00046 IF (IPLOT.GT.0) THEN
00047 WRITE(10,109)
00048 WRITE(10,'((2X,4(2X,F10.5)))')
00049 & (((T(I)*1000.0),DMPDT(I),THRUST(I),PHI(I)),I=1,N,IPLOT)
00050 ENDIF
00051 C
00052 100 FORMAT(1H1/,14X,5(1H*), ' SOLUTION PROFILE ',5(1H*),
00053 & //7X,' T ',4X,' DMPDT ',6X,' THRUST ',8X,' PHI ',
00054 & /7X,' (m-sec)',4X,' (lbm/s)',6X,' (lb)',/)
00055 109 FORMAT(7X,' T ',4X,' DMPDT ',6X,' THRUST ',8X,' PHI ')
00056 199 RETURN
00057 END

```

APPENDIX B - TEA PROGRAM LISTING

```

00001 C=====
00002 SUBROUTINE SPC(T,DMPDT,T1P0,P1P,THRUST,PHI,MODE)
00003 C
00004 C      Single Point Calculation (SPC) Routine
00005 C-----
00006 C
00007 COMMON /CHECK/ ICHECK, INDEX
00008 COMMON /COEFX/ BETA, CSIGMA
00009 COMMON /LAST1/ TLAST
00010 COMMON /LIST1/ X0, Y0,
00011 & X1, Y1, NX1, NY1,
00012 & X2, Y2,
00013 & X3, Y3,
00014 & X4, Y4,
00015 & Z1, NZ1, DZ
00016 COMMON /LIST2/ GAMMA, RBAR, TINF, PINF, PBACK
00017 COMMON /LIST3/ ALPHA, U
00018 COMMON /LIST4/ E, F, G
00019 COMMON /LIST5/ P1S, T1S, V1S, D1S, Z1S
00020 COMMON /LIST6/ PE, TE, VE, RE
00021 COMMON /LIST7/ PM, TM, VM, RM
00022 COMMON /LIST8/ DRDT, DEDT, DKEOLD, VENEW, DVE
00023 C
00024 DIMENSION B(50), BSTAR(50), E(15,50), F(15,50),
00025 & G(15,50), PE(50), PM(50), RE(50), RM(50),
00026 & TE(50), TM(50), VE(50), VM(50), XIHAT(50), Z(50),
00027 & BI(50), BII(50), DRDT(50), DPDT(50), DEDT(50), DVDT(50)
00028 REAL*8 V1P,V1S,R2,THETA1,DZ,B,BI,BII,THETA2,XIHAT
00029 REAL*8 SURGE,DELTA,DM3DT,DM4DT,D1S,D1P,A1S,A1PT
00030 REAL*8 T1S,C1S,PE,PM,VE,VM,RE,RM,DMSDT
00031 REAL*8 BVALUE,CVALUE,B24AC,C8
00032 REAL*8 DM1DT,FLUXP,FLUXM,FLUXMI,FLUXMJ
00033 C
00034 C---INTERNAL FUNCTION DEFINITIONS
00035 C
00036 CP(G,R) = R*G/(G-1.0)
00037 F2(G,Z) = 1.0 + 0.5*(G-1.0)*Z*Z
00038 F3(G,Z) = F2(G,Z)**(G/(G-1.0))
00039 FZ0(PM,PE,E1,E2) = PM*E1 + PE*E2
00040 FZ1(RM,RE,VM,VE,C1,C2,C3,C4) =
00041 & RM*VM*C1 + RE*VM*C2 + RM*VE*C3 + RE*VE*C4
00042 FZ2(RM,RE,VM,VE,G1,G2,G3,G4,G5,G6) =
00043 & RM*G1*VM*VM + RM*G2*VE*VE + RM*G3*VE*VM +
00044 & RE*G4*VM*VM + RE*G5*VE*VE + RE*G6*VE*VM
00045 FZETA(Z,C1,C2,C3,C4) = C1*Z**4. + C2*Z**2.5 + C3*Z + C4
00046 FPZETA(Z,C1,C2,C3) = 4.*C1*Z**3. + 2.5*C2*Z**1.5 + C3
00047 FPPZETA(Z,C1,C2) = 12.*C1*Z**2. + 3.75*C2*Z**0.5
00048 GFT(T)=1.3825+0.10173*T*(1.-1.5638*T*(1.0-.4016*T*(1.-.1304*T)))
00049 H1G(Z) = (4531. + 1309.*Z**10. - 9240.*Z**8.5 + 22440.*Z**7.
00050 & -19040.*Z**5.5)/13090.0
00051 H2G(Z) = (729. + 1122.*Z**10. - 7920.*Z**8.5 + 22440.*Z**7.
00052 & -32640.*Z**5.5 + 25245.*Z**4. - 8976.*Z**2.5)/ 3740.0
00053 H3G(Z) = (2727. - 3927.*Z**10. + 27720.*Z**8.5 - 72930.*Z**7.
00054 & +85680.*Z**5.5 - 39270.*Z**4.)/13090.0
00055 H4G(Z) = ( 6561. - 2618.*Z**10. + 18480.*Z**8.5 - 56100.*Z**7.
00056 & +95200.*Z**5.5 - 98175.*Z**4. + 62832.*Z**2.5
00057 & -26180.*Z)/26180.0

```

APPENDIX B - TEA PROGRAM LISTING

```

00058      H1L(Z) = -(H1G(Z) - 4531.0/13090.0)
00059      H2L(Z) = -(H2G(Z) - 729.0/ 3740.0)
00060      H3L(Z) = -(H3G(Z) - 2727.0/13090.0)
00061      H4L(Z) = -(H4G(Z) - 6561.0/26180.0)
00062      C
00063      C---GLOBAL PARAMETER INITIALIZATION
00064      C
00065          ITN   = 0
00066          LIMIT = 50
00067          GC    = 32.174
00068          W     = Y2
00069          SCALE = FLOAT(NX1)*FLOAT(NY1)
00070          N     = NZ1+1
00071          DZ    = Z1/FLOAT(NZ1)
00072      C
00073      C---CONDITIONS FOR FREE-STREAM
00074      C
00075          10 ALPHAR = ALPHA*3.1415/180.0
00076          VINP    = U*SIN(ALPHAR)
00077          DUyDT   = DUDT*SIN(ALPHAR)
00078          DINP    = PINP/(RBAR*TINP/GC)
00079          POINP   = PINP+0.5*VINP*VINP*DINP/GC
00080          TOINP   = TINP+0.5*VINP*VINP/CP(GAMMA, RBAR)
00081          AINP    = X0*Y0
00082          DMIDT   = AINP*VINP*DINP
00083      C
00084      C---EVALUATE PRIMARY NOZZLE CONDITIONS
00085      C
00086          A1P = X1*Y1
00087          A1PT= A1P*FLOAT(NX1)*FLOAT(NY1)
00088          ZZ0 = GAMMA/(GAMMA-1.0)
00089          ZZ1 = (GAMMA-1.0)/GAMMA
00090          ZZ2 = (GAMMA+1.0)/2.0
00091          ZZ3 = 2.0*GAMMA*(GAMMA+1.0)
00092          ZZ4 = (DMPDT/(A1PT*PBACK*GC))**2.0
00093          ZZ4 = ZZ4*T1P0*RBAR*(GAMMA-1.0)/(2.0*GAMMA)
00094          PRN = (0.5+0.5*SQRT(1.0+4.0*ZZ4))**ZZ0
00095          XPRN= ZZ2**ZZ0
00096      C
00097      C CHECK FOR CHOKED FLOW....
00098          IF (PRN.LT.XPRN) GO TO 17
00099      C
00100      C CHOKED NOZZLE FLOW OPERATIONS...
00101          P1P0 = 1.88076*(DMPDT/A1PT)*SQRT(T1P0)
00102          PRN  = P1P0/PBACK
00103          Z1P  = 1.0
00104          P1P  = P1P0/F3(GAMMA,Z1P)
00105          YPRN = P1P0/P1P
00106          FORCE1P= DMPDT*(2.0/GC)*SQRT((T1P0*RBAR)/ZZ3)
00107          FORCE1P= FORCE1P*(GAMMA + 1.0 - XPRN/PRN)
00108          GO TO 19
00109      C
00110      C SUBSONIC NOZZLE COMPUTATIONS...
00111      17  ZZ4 = (DMPDT/(A1PT*P1P*GC))**2.0
00112          ZZ4 = ZZ4*T1P0*RBAR*(GAMMA-1.0)/(2.0*GAMMA)
00113          YPRN = (0.5+0.5*SQRT(1.0+4.0*ZZ4))**ZZ0
00114          Z1P  = SQRT((2.0/(GAMMA-1.0))*(YPRN**ZZ1 - 1.0))

```

APPENDIX B - TEA PROGRAM LISTING

```

00115      P1P0 = P1P*YPRN
00116      PRN = P1P0/PBACK
00117      PRN = AMAX1(1.,PRN)
00118      FORCE1P= DMPDT*(SQRT(T1P0))/GC
00119      FORCE1P= FORCE1P*SQRT((2.*RBAR*ZZ0)*(1.0-(1./PRN)**ZZ1))
00120  19 CONTINUE
00121      T1P = T1P0/F2(GAMMA,Z1P)
00122      D1P = P1P/(T1P*RBAR/GC)
00123      C1P = SQRT(GAMMA*RBAR*T1P)
00124      V1P = Z1P*C1P
00125      DMPDT = D1P*V1P*A1PT
00126  C
00127  C----PREDICT SECONDARY FLOW PROPERTIES
00128  C
00129      A1S = (X3*Y3)-A1PT
00130      P1S0=POINF
00131      T1S0=TOINF
00132  C STATION 1-S INITIAL VELOCITY ESTIMATE
00133      IF (MODE.EQ.0) V1S = 1.0
00134      IF (MODE.EQ.1) V1S = VENEW
00135  C ITERATE ON ACTUAL SOLUTION
00136  20 ITN = ITN + 1
00137      T1S = T1S0 - 0.5*(V1S**2.0)/CP(GAMMA, RBAR)
00138      P1S = P1S0*(T1S/T1S0)**(GAMMA/(GAMMA-1.0))
00139      D1S = P1S/(RBAR*T1S/GC)
00140      DMSDT = D1S*V1S*A1S
00141      ER = DMSDT/DMPDT
00142      ENERGY1S = 0.5*D1S*V1S**3.0
00143  C
00144  C---MIXING REGION PREDICTIONS
00145  C
00146      AREA3 = X3*Y3
00147      DM1DT = DMPDT + DMSDT
00148      PM(1) = P1P
00149      PE(1) = P1S
00150      RM(1) = D1P/GC
00151      RE(1) = D1S/GC
00152      VM(1) = V1P
00153      VE(1) = V1S
00154  C
00155  C--- VIRTUAL GRID INITIALIZATION
00156  C
00157      R2 = V1S/V1P
00158      THETA1 = DATAN(0.4*(1-R2)*(0.416+0.134*R2)/(1+R2))
00159      BI(1) = A1P/(W**2.0)
00160      BI(2) = BI(1) - DZ*DTAN(THETA1)
00161      IF(BI(2).LE.0.0) BI(2)=0.0
00162      BII(1) = BI(1)
00163      BMAX = X2/2.0
00164  C
00165  C COMPUTE OUTER JET EXPANSION ANGLE
00166      C1 = BI(2)*D1P*V1P + (BMAX-BI(2))*D1S*V1S
00167      C2 = 0.45*D1P*V1P + 0.55*D1P*V1S - D1S*V1S
00168      B(2) = ((DM1DT/(2.0*SCALE*W))-C1)/C2
00169      BII(2)= B(2)+BI(2)
00170      THETA2= DATAN ((BII(2)-BII(1))/DZ)
00171  C

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00172 C   COMPUTE FINAL GRID BOUNDARIES
00173     DO 34 I = 2,N
00174         Z(I) = DZ*FLOAT(I-1)
00175         BI(I) = BI(I) - Z(I)*DTAN(THETA1)
00176         IF(BI(I).LE.0.0) BI(I)=0.0
00177         BII(I) = BII(I) + Z(I)*DTAN(THETA2)
00178         IF(BII(I).GT.BMAX) BII(I)=BMAX
00179         B(I) = BII(I) - BI(I)
00180         XIHAT(I) = (BMAX-BI(I))/B(I)
00181     34 CONTINUE
00182 C
00183 C   COMPUTE SIGMA
00184 C     SIGMA = CSIGMA*Z(N)*144.0/(1.0+Z1P)
00185 C     SIGMA = CSIGMA*(((1.0+0.23*Z1P)*12.0/Z(N))**2.0)
00186 C
00187 C   COMPUTE SELF-SIMILAR PROFILE INTEGRALS FOR THE NEW JET
00188     DO 37 I=2,N
00189         BIB = BI(I)/B(I)
00190         E(I,1) = BIB + 1.00
00191         E(I,2) = XIHAT(I) - 1.00
00192         F(I,1) = BIB + 0.45
00193         F(I,2) = 0.0
00194         F(I,3) = 0.55
00195         F(I,4) = XIHAT(I) - 1.0
00196         G(I,1) = (BIB + 243.0/770.0)
00197         G(I,2) = (320.0/770.0)
00198         G(I,3) = (414.0/1540.0)
00199         G(I,4) = 0.0
00200         G(I,5) = (XIHAT(I) - 1.0)
00201         G(I,6) = 0.0
00202     37 CONTINUE
00203     INCLUDE 'XCHECK1.FOR'
00231 C
00232 C---SKIP FINITE VOLUME INITIALIZATION IF MODE > 0
00233 C
00234     IF (MODE.EQ.1) GO TO 40
00235 C
00236 C---INITIALIZATION OF FIELD VARIABLES
00237 C
00238     DO 39 I = 1,N-1
00239         J = I+1
00240         RE(J) = RE(I)
00241         PE(J) = PE(I)
00242         DO 38 K=1,3
00243             VE(J) = VE(I)
00244             C8 = 0.5*VE(I)*VE(I)
00245             & + GAMMA/(GC*(GAMMA-1.0))*(PE(I)/RE(I)-PE(J)/RE(J))
00246             IF(C8.GT.0.0) VE(J) = SQRT(2*C8)
00247         IF (I.EQ.1) THEN
00248             FLUXRI = RM(I)*VM(I)*A1PT + RE(I)*VE(I)*A1S
00249             FLUXPI = PM(I)*VM(I)*A1PT + PE(I)*VE(I)*A1S
00250             FLUXMI = (PM(I)+RM(I)*VM(I)*VM(I))*A1PT
00251             & + (PE(I)+RE(I)*VE(I)*VE(I))*A1S
00252         ELSE
00253             FLUXRI = 2.0*SCALE*W*B(I)*
00254             & FZ1(RM(I),RE(I),VM(I),VE(I),F(I,1),F(I,2),F(I,3),F(I,4))
00255             FLUXPI = 2.0*SCALE*W*B(I)*

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00256      &      FZ1(PM(I),PE(I),VM(I),VE(I),F(I,1),F(I,2),F(I,3),F(I,4))
00257      FLUXMI = 2.0*SCALE*W*B(I)*(
00258      &      FZ2(RM(I),RE(I),VM(I),VE(I),G(I,1),G(I,2),G(I,3),G(I,4),
00259      &      G(I,5),G(I,6))
00260      &      +FZ0(PM(I),PE(I),E(I,1),E(I,2)))
00261      ENDIF
00262      C1 = (G(J,3)+G(J,6))/(G(J,1)+G(J,4))
00263      C2 = (F(J,1)+F(J,2))/(G(J,1)+G(J,4))
00264      C3 = (G(J,2)+G(J,5))/(G(J,1)+G(J,4))
00265      C4 = (E(J,1)+E(J,2))/(G(J,1)+G(J,4))
00266      C5 = (F(J,3)+F(J,4))/(G(J,1)+G(J,4))
00267      BVALUE= VE(J)*C1 - (FLUXMI/FLUXRI)*C2
00268      CVALUE= VE(J)*VE(J)*C3 + (FLUXPI/FLUXRI)*C4
00269      &      - VE(J)*(FLUXMI/FLUXRI)*C5
00270      B24AC = (BVALUE**2.0) - 4.0*CVALUE
00271      IF (B24AC.LT.0.0) THEN
00272          WRITE(*,900) 1
00273          INCLUDE 'XCHECK2.FOR'
00295      ENDIF
00296      VM(J) = -0.5*(BVALUE+DSQRT(B24AC))
00297      C6 = FLUXRI/(2.0*SCALE*W*B(J)*(F(J,1)+F(J,2)))
00298      C7 = VE(J)*(F(J,3)+F(J,4))/(F(J,1)+F(J,2))
00299      C8 = FLUXPI/(2.0*SCALE*W*B(J)*(F(J,1)+F(J,2)))
00300      RM(J) = C6/(VM(J)+C7)
00301      RE(J) = RM(J)
00302      PM(J) = C8/(VM(J)+C7)
00303      PE(J) = PM(J)
00304      38 CONTINUE
00305      39 CONTINUE
00306      C
00307      C---DERIVATIVE ESTIMATES
00308      C
00309      40 DT = T-TLAST
00310      C
00311      C ...SKIP DERIVATIVE COMPUTATIONS IF DT=0
00312      IF(DT.LE.0.0) GO TO 43
00313      C
00314      C ...NO DERIVATIVES ARE NEEDED FOR QUASI-STEADY FLOW
00315      IF(MODE.EQ.0) GO TO 43
00316      C
00317      C ...PROCEED WITH DERIVATIVE COMPUTATIONS
00318      DO 42 I = 1,N-1
00319          J = I+1
00320      C
00321      C ...UPDATE ENTRAINED VELOCITY
00322      VE(J) = VE(I)
00323      C8 = 0.5*VE(I)*VE(I)
00324      &      + GAMMA/(GC*(GAMMA-1.0))*(PE(I)/RE(I)-PE(J)/RE(J))
00325      IF(C8.GT.0.0) VE(J) = SQRT(2.0*C8)
00326      C
00327      C
00328      C ...COMPUTE STATION 'I' FLUXES
00329      IF (I.EQ.1) THEN
00330          FLUXRI = DMIDT/(2.0*SCALE*W*GC)
00331          FLUXMI = ((A1PT*(P1P+D1P*V1P*V1P/GC))
00332      &      + (A1S*(P1S+D1S*V1S*V1S/GC)))/(2.0*SCALE*W)
00333          FLUXPI = ((A1PT*P1P*V1P)+(A1S*P1S*V1S))/(2.0*SCALE*W)

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00334      ELSE
00335          FLUXRI = B(I)*FZ1(RM(I),RE(I),VM(I),VE(I),
00336      &          F(I,1),F(I,2),F(I,3),F(I,4))
00337          FLUXMI = B(I)*(FZ2(RM(I),RE(I),VM(I),VE(I),
00338      &          G(I,1),G(I,2),G(I,3),G(I,4),
00339      &          G(I,5),G(I,6))
00340      &          +FZO(PM(I),PE(I),E(I,1),E(I,2)))
00341          FLUXPI = B(I)*FZ1(PM(I),PE(I),VM(I),VE(I),
00342      &          F(I,1),F(I,2),F(I,3),F(I,4))
00343      ENDIF
00344  C
00345  C      ... COMPUTE STATION 'J' FLUXES ...
00346      FLUXRJ = B(J)*FZ1(RM(J),RE(J),VM(J),VE(J),
00347      &          F(J,1),F(J,2),F(J,3),F(J,4))
00348      FLUXMJ = B(J)*(FZ2(RM(J),RE(J),VM(J),VE(J),
00349      &          G(J,1),G(J,2),G(J,3),G(J,4),
00350      &          G(J,5),G(J,6))
00351      &          +FZO(PM(J),PE(J),E(J,1),E(J,2)))
00352      FLUXPJ = B(J)*FZ1(PM(J),PE(J),VM(J),VE(J),
00353      &          F(J,1),F(J,2),F(J,3),F(J,4))
00354  C
00355  C      ... COMPUTE PRIMARY FLOW DERIVATIVES ...
00356      DEDT(I) = DVE/DT
00357      DRDT(I) = (FLUXRI - FLUXRJ)/(BMAX*DZ)
00358      DPDT(I) = (FLUXPI - FLUXPJ)/(BMAX*DZ)
00359      CDVDT = 0.0
00360      C1 = (F(J,3)+F(J,4))/(F(J,1)+F(J,2))
00361      C2 = C1*DEDT(I)*CDVDT - (DRDT(I)/RM(J))*(VM(J)+VE(J)*C1)
00362      DVDT(I) = (FLUXMI - FLUXMJ)/(B(J)*DZ) - C2
00363  C
00364  C      ... ADVANCE PRIMARY FLOW FORWARD IN TIME ...
00365      RM(J) = RM(J) + DRDT(I)*DT
00366      RE(J) = RM(J)
00367      PM(J) = PM(J) + DPDT(I)*DT
00368      PE(J) = PM(J)
00369      VM(J) = VM(J) + DVDT(I)*DT
00370  42 CONTINUE
00371  C
00372  C      COMPUTE THE JET STREAMLINE
00373  43 DO 45 J = 2,N
00374      ISTOP= 0
00375      ZETA = BI(1)/B(J)
00376      C1 = 0.25*(VM(J)-VE(J))
00377      C2 = 0.80*(VE(J)-VM(J))
00378      C3 = VM(J)
00379      C4 = (RE(1)/RE(J))*((BMAX-BI(1))/B(J))*V1S
00380      &      - C1 - C2 - C3 - ((BMAX/B(J)) - 1.)*VE(J)
00381  44      ISTOP = ISTOP + 1
00382      C5 = FZETA(ZETA,C1,C2,C3,C4)/FPZETA(ZETA,C1,C2,C3)
00383      C6 = 1- FZETA(ZETA,C1,C2,C3,C4)*FPPZETA(ZETA,C1,C2)
00384      &      /FPZETA(ZETA,C1,C2,C3)**2.0
00385      DELTA = -C5/C6
00386      ZETA = ZETA + DELTA
00387      BSNEW = ZETA*B(J)
00388      IF (BSNEW.GE.BMAX) THEN
00389          BSTAR(J) = BMAX
00390          GO TO 45

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00391      ENDIF
00392      IF((ABS(DELTA).GE.0.000001).AND.(ISTOP.LT.50)) GO TO 44
00393      BSTAR(J) = BSNEW
00394      45 CONTINUE
00395      C
00396      C---KINETIC ENERGY EXCHANGE
00397      C
00398      ZETA = BSTAR(N)/B(N)
00399      ZSTAR = BMAX/B(N)
00400      C1 = (H1G(ZETA) - (0.55 + 0.25*ZETA**4.-0.8*ZETA**2.5))
00401      & *VE(N)**3.0
00402      C2 = (H3G(ZETA) - (0.45-(0.25*ZETA**4.-0.8*ZETA**2.5+ZETA)))
00403      & *VM(N)*VE(N)**2.0
00404      C3 = H2G(ZETA)*VE(N)*VM(N)**2.0
00405      C4 = H4G(ZETA)*VM(N)**3.0
00406      DKE = B(N)*RM(N)*GC*(C1+C2+C3+C4)
00407      C1 = H1L(ZETA)*VE(N)**3. + H2L(ZETA)*VE(N)*VM(N)**2.
00408      & + H3L(ZETA)*VM(N)*VE(N)**2. + H4L(ZETA)*VM(N)**3.
00409      C2 = (0.25*ZETA**4. - 0.8*ZETA**2.5 + ZETA)*VM(N)**3.
00410      & + (-0.25*ZETA**4. + 0.8*ZETA**2.5)*VE(N)*VM(N)**2.
00411      PLOSS = -B(N)*RM(N)*GC*(C1-C2)
00412      DKE = DKE + SIGMA*PLOSS
00413      CHANGE = DKE - DKEOLD
00414      VSTAR = ((ENERGY1S+CHANGE)/(0.5*D1S))
00415      IF(VSTAR.LT.0.0) THEN
00416          WRITE(*,900) 2
00417          INCLUDE 'XCHECK3.FOR'
00418      ENDIF
00419      VENUEW = (ABS(VSTAR))**(1./3.)
00420      DVE = VENUEW-V1S
00421      DKEOLD = DKE
00422      C
00423      C---ASSIGN MIXING REGION EXIT CONDITIONS
00424      C
00425      ZZZ = (2.0*SCALE*W*B(N))/AREA3
00426      V3 = ZZZ*(0.45*VM(N) + (XIHAT(N)-0.45)*VE(N))
00427      D3 = RM(N)*GC
00428      IF (D3.LT.0.0) WRITE(*,900) 3
00429      IF (D3.GE.1.0) WRITE(*,900) 4
00430      P3 = PM(N)
00431      T3 = P3/(RBAR*D3/GC)
00432      IF (T3.LT.0.0) WRITE(*,900) 5
00433      C3 = SQRT(GAMMA*RBAR*T3)
00434      Z3 = V3/C3
00435      P30 = P3*F3(GAMMA,Z3)
00436      T30 = T3*F2(GAMMA,Z3)
00437      DM3DT= D3*V3*AREA3
00438      C
00439      C---DIFFUSER PREDICTIONS
00440      C
00441      50 AREA4 = X4*Y4
00442      P40 = P30
00443      T40 = T30
00444      IF(MODE.EQ.0) THEN
00445          P4 = PBACK
00446          IF(P40.LT.P4) WRITE(*,900) 6
00447          Z4 = SQRT((2.0/(GAMMA-1.0))

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00468      &          *(((P40/P4)**((GAMMA-1.0)/GAMMA))-1.0))
00469      T4 = T40/F2(GAMMA,Z4)
00470      D4 = P4/(RBAR*T4/GC)
00471      C4 = SQRT(GAMMA*RBAR*T4)
00472      V4 = Z4*C4
00473      ELSE
00474      C1 = 0.5/(GAMMA-1.0)
00475      C2 = (GAMMA/(GAMMA-1.0))*GC*AREA4*P30/DM3DT
00476      C3 = CP(GAMMA, RBAR)*T30
00477      V4 = (C2-SQRT(C2*C2-4.0*C1*C3))/(2.0*C1)
00478      D4 = DM3DT/(V4*AREA4)
00479      P4 = P40 - 0.5*D4*V4*V4/GC
00480      T4 = T40 - 0.5*V4*V4/CP(GAMMA, RBAR)
00481      C4 = SQRT(GAMMA*RBAR*T4)
00482      ENDIF
00483      DM4DT = D4*V4*AREA4
00484      C
00485      C--- CHECK FOR CONTINUITY
00486      C
00487      EPSILON = 0.00005
00488      SURGE = (DM4DT - DM3DT)/(D1S*A1S)
00489      IF(MODE.EQ.1) GO TO 70
00490      IF (ABS(SURGE).LE.EPSILON) THEN
00491      GO TO 70
00492      ELSE
00493      V1S = V1S + SURGE
00494      INCLUDE 'XCHECK4.FOR'
00505      IF(ITN.LT.LIMIT) GO TO 20
00506      ENDIF
00507      C---THRUST AND THRUST AUGMENTATION RESULTS
00508      C
00509      70 THRUST = (DM4DT*(V4/(BETA**2.)-VINP)/(GC))
00510      &          + AREA4*(PBACK-PINF)
00511      PHI      = THRUST/FORCE1P
00512      C
00513      C---PRINT OPTION
00514      C
00515      IF(ICHECK.LT.100) GO TO 999
00516      WRITE (6,200) T
00517      WRITE (6,201) AINF, A1PT, A1S, AREA3, AREA4,
00518      &          VINP, V1P, V1S, V3, V4,
00519      &          PINF, P1P, P1S, P3, P4,
00520      &          POINF, P1P0, P1S0, P30, P40,
00521      &          TINF, T1P, T1S, T3, T4,
00522      &          TOINF, T1P0, T1S0, T30, T40,
00523      &          DINF, D1P, D1S, D3, D4,
00524      &          DMIDT, DMPDT, DMSDT, DM3DT, DM4DT
00525      WRITE (6,202) PRN, XPRN
00526      IF(MODE.EQ.0) WRITE (6,203) SURGE, ITN, LIMIT
00527      WRITE (6,204)
00528      WRITE (6,207)((I,Z(I),BI(I),BII(I),BSTAR(I)),I=2,N)
00529      WRITE (6,206)
00530      WRITE (6,207)((I,RM(I),PM(I),VM(I),VE(I)),I=1,N)
00531      WRITE (6,208)
00532      WRITE (6,207)((I,DRDT(I),DPDT(I),DVDT(I),DEDT(I)),I=1,N-1)
00533      WRITE (6,209) THETA1,THETA2,BI(1),BMAX
00534      WRITE (6,210) THRUST,FORCE1P,PHI

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00535 200 FORMAT(1H1,/,19X,'***** SINGLE POINT CALCULATION *****',
00536 & /,29X,'T = ',F8.5,' sec'/)
00537 201 FORMAT( /,3X,'FIELD VARIABLE PROFILE:',/
00538 & /,3X,'Station -> Infinity',6X,'1P',10X,'1S',10X,
00539 & '3 4',/
00540 & /,3X,'AREA ',2X,5(F10.5,2X),'FT',
00541 & /,3X,'V ',2X,5(F10.5,2X),'FT/S',
00542 & /,3X,'P ',2X,5(F10.5,2X),'LBF/FT2',
00543 & /,3X,'PO ',2X,5(F10.5,2X),'LBF/FT2',
00544 & /,3X,'T ',2X,5(F10.5,2X),'DEG-R',
00545 & /,3X,'TO ',2X,5(F10.5,2X),'DEG-R',
00546 & /,3X,'RHO ',2X,5(F10.5,2X),'LBM/FT3',
00547 & /,3X,'MDOT ',2X,5(F10.5,2X),'LBM/S')
00548 202 FORMAT(7X,'NOTES:',/10X,'Nozzle Pressure Ratio is ',F8.5,
00549 & ' (Choked NPR is ',F8.5,' )')
00550 203 FORMAT( 10X,'Station 3-4 SURGE error is ',F12.8,
00551 & /,10X,'Solution obtained in ',I3,' iterations, limit is ',I3)
00552 204 FORMAT(/,3X,'FINITE VOLUME PROFILE',/,5X,'Station Z',
00553 & 10X,'B,inner',7X,'B,outer',8X,'B,jsl ')
00554 206 FORMAT(/,5X,'Station',4X,'Rho',11X,'P',13X,'Vm',12X,'Ve')
00555 207 FORMAT(6X,I3,2X,E12.5,2X,E12.5,2X,E12.5,2X,E12.5)
00556 208 FORMAT(/,5X,
00557 & 'Element D(Rho)/DT D(P)/DT D(Vm)/DT D(Ve)/DT')
00558 209 FORMAT(7X,'NOTES:',
00559 & /10X,'Inner jet expansion, Thetal ',F8.5,' radians',
00560 & /10X,'Outer jet expansion, Theta2 ',F8.5,' radians',
00561 & /10X,'Initial jet with, B0, ',F8.5,' Ft',
00562 & /10X,'Allowable jet width, Bmax, ',F8.5,' Ft')
00563 210 FORMAT( /,3X,'PREDICTED THRUST AND PERFORMANCE:',
00564 & //,5X,'Total ejector thrust = ',F12.5,' Lb',
00565 & /,5X,'Isentropic primary thrust = ',F12.5,' Lb',
00566 & /,5X,'Thrust augmentation ratio = ',F12.5)
00567 900 FORMAT(/5X,'$$$ TEA FATAL ERROR # ',I2,', $$$'/)
00568 999 RETURN
00569 END

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APPENDIX B - TEA PROGRAM LISTING

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00001 C=====
00002 C   XCHECK1.FOR
00003 C-----
00004 C   PRINT MIXING REGION DATA FOR DEBUG CHECKS
00005 C-----
00006   1000 IF(ICHECK.LT.1000) GO TO 1020
00007         WRITE(6,1010) T,ITN
00008         WRITE(6,1011)
00009         DO 1001 I=2,N
00010   1001     WRITE(6,1012) (I,(E(I,J),J=1,2))
00011           WRITE(6,1013)
00012           DO 1002 I=2,N
00013   1002     WRITE(6,1014) (I,(F(I,J),J=1,4))
00014           WRITE(6,1015)
00015           DO 1003 I=2,N
00016   1003     WRITE(6,1016) (I,(G(I,J),J=1,6))
00017   1010 FORMAT(1H1,/10X,'*** T = ',F10.5,' ITN = ',I5)
00018   1011 FORMAT(/,33X,'> SELF-SIMILAR PROFILE EVALUATION <',
00019         &      /,3X,'Z-POINT   E(1)           E(2)')
00020   1012 FORMAT(5X,I2,1X,2(3X,F7.3))
00021   1013 FORMAT(/,3X,'Z-POINT   F(1)           F(2)           F(3)           ',
00022         &      'F(4)')
00023   1014 FORMAT(5X,I2,1X,4(3X,F7.3))
00024   1015 FORMAT(/,3X,'Z-POINT   G(1)           G(2)           G(3)           ',
00025         &      'G(4)           G(5)           G(6)')
00026   1016 FORMAT(5X,I2,1X,6(3X,F7.3))
00027   1020 CONTINUE

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APPENDIX B - TEA PROGRAM LISTING

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00001 C=====
00002 C   XCHECK2.FOR
00003 C-----
00004 C   PRINT VELOCITY INITIALIZATION DATA FOR DEBUG CHECKS
00005 C-----
00006   2000 IF(ICHECK.LT.500) GO TO 2060
00007         WRITE(6,2010) T,I,J
00008         WRITE(6,2020) C1,C2,C3,C4,C5
00009         WRITE(6,2050) THETA1,THETA2
00010         WRITE(6,2030) FLUXRI,FLUXMI,FLUXPI
00011         WRITE(6,2040) VE(J),BVALUE,CVALUE,B24AC
00012   2010 FORMAT(///,5X,'*** T = ',F7.4,' ; I = ',I2,' J = ',I2)
00013   2020 FORMAT(/,5X,'C1',8X,'C2',8X,'C3',8X,'C4',8X,'C5',
00014         &/,5X,5(F10.4,2X))
00015   2030 FORMAT(/2X,'FLUXRI = ',E12.4,
00016         &      /2X,'FLUXMI = ',E12.4,/2X,'FLUXPI = ',E12.4)
00017   2040 FORMAT(/2X,'VE(J) = ',F10.4,/
00018         &      2X,'B = ',E12.4,' C = ',E12.4,' B24AC = ',E12.4)
00019   2050 FORMAT(/5X,'THETA1 = ',F10.5,' THETA2 = ',F10.5)
00020   2060 CONTINUE
00021 C=====

```


APPENDIX B - TEA PROGRAM LISTING

```

00001 C=====
00002 C   XCHECK3.FOR
00003 C-----
00004 C   KINETIC ENERGY EXCHANGE ERRORS
00005 C   Print out all kinetic energy information if the program bombs.
00006 C   This error by resetting the KE-CHANGE and re-computing VSTAR
00007 C-----
00008       WRITE(*,*)
00009       WRITE(*, '(/5X,38H*** ERROR DURING CALCULATIONS FOR T = ,
00010 &          F10.5)') T
00011       WRITE(*, '(/10X,10HDKE      = ,F15.3,/10X,10HDKEOLD = ,F15.3,
00012 &          /10X,10HSIGMA    = ,F15.3,/10X,10HPLOSS   = ,F15.3,
00013 &          /10X,10HENERGY1S= ,F15.3,/10X,10HCHANGE  = ,F15.3,
00014 &          /10X,10HVSTAR   = ,F15.3)')
00015 &          DKE,DKEOLD,SIGMA,PLOSS,ENERGY1S,CHANGE,VSTAR
00016       CHANGE = -0.999*ENERGY1S
00017       WRITE(*, '(/5X,38H*** PROCEED W/ CHANGE = -0.999ENERGY1S)')
00018       VSTAR = ((ENERGY1S+CHANGE)/(0.5*D1S))
00019       WRITE(*, '(/5X,19H*** NEW VSTAR IS = ,F15.3//)') VSTAR
00020 C=====

```

APPENDIX B - TEA PROGRAM LISTING

```

00001 C=====
00002 C   XCHECK4.FOR
00003 C-----
00004 C   PRINT ENTRAINED VELOCITY AND SURGE FOR ITERATIVE PROCESS
00005 C-----
00006 4000 IF(ICHECK.LT.1000) GO TO 4020
00007       WRITE(6,4010) V1S,SURGE
00008 4010 FORMAT(/,5X,'V1S = ',F10.3,'    SURGE = ',F10.3)
00009 4020 CONTINUE
00010 C-----

```

APPENDIX C - TEST CASE INPUT LISTINGS

```

C----- CASE1.DAT ---
C
C   Case study input file for TEA.FOR transient ejector analysis
C   routine. Here, a single step function is prescribed that
C   corresponds with one of the STOVLE ejector tests run in June 1987.
C   This file assumes the default BACK and DISP parameters in the TEA.FOR
C   source code are appropriate.
C-----

```

CASE banner.

Test for step change in primary flow for STOVLE ejector design.

GEOMETRIC approximation for the ejector.

```

X0      Y0
0009.36000, 0001.25000
X1      Y1      NX1      NY1
0000.10801, 0000.10801, 00012, 00003
X2      Y2
0000.78000, 0000.34700
X3      Y3
0009.36000, 0001.04100
X4      Y4
0009.36000, 0001.87500
Z1      NZ
0000.90000, 00005

```

COEFFICIENTS for solution execution.

```

ITYPE      BETA      CSIGMA
00001,      0001.0550, 0000.30000

```

PRIMARY nozzle discharge conditions.

SPECIFY states at each time step.

```

T      MDOT1P      T1P0      P1P
0000.00010, 0018.70000, 0769.70000, 2219.78000
0000.00020, 0018.70000, 0769.70000, 2219.78000
0000.00030, 0018.70000, 0769.70000, 2219.78000
0000.00040, 0018.70000, 0769.70000, 2219.78000
0000.00050, 0018.70000, 0769.70000, 2219.78000
0000.00060, 0021.85000, 0760.60000, 2250.92000
0000.00070, 0021.85000, 0760.60000, 2250.92000
0000.00080, 0021.85000, 0760.60000, 2250.92000
0

```

```

C-----

```

APPENDIX C - TEST CASE INPUT LISTINGS

```

00001
00002 C----- CASE2.DAT ---
00003 C
00004 C   This case study has the same basic conditions as CASE1.DAT, but includes
00005 C   the use of some optional macros.
00006 C
00007 C-----
00008
00009 CASE banner.
00010   Test for step change in primary flow for STVOL ejector design.
00011
00012 DISPlay parameters for printing and plotting output.
00013 ICHECK      INDEX      IPLOT
00014 00100,      00001,      00001
00015
00016 GEOMetric approximation for the ejector.
00017 X0           Y0
00018 0009.36000, 0001.25000
00019 X1           Y1           NX1      NY1
00020 0000.10801, 0000.10801, 00012, 00003
00021 X2           Y2
00022 0000.78000, 0000.34700
00023 X3           Y3
00024 0009.36000, 0001.04100
00025 X4           Y4
00026 0009.36000, 0001.87500
00027 Z1           NZ
00028 0000.90000, 00005
00029
00030 COEfficients for solution execution.
00031 ITYPE      BETA      CSIGMA
00032 00001,      0001.0550, 0000.30000
00033
00034 FREE stream fluid conditions.
00035 TINF      PINF      GAMMA      RBAR      UINF      ALPHA
00036 0542.80000, 2067.84000, 0001.40000, 1714.54130, 0000.00000, 0090.00000
00037
00038 BACKpressure for ejector discharge
00039 2067.84000
00040
00041 PRIMary nozzle discharge conditions.
00042 SPECify states at each time step.
00043 T      MDOT1P      T1P0      P1P
00044 0000.00010, 0018.70000, 0769.70000, 2219.78000
00045 0000.00020, 0018.70000, 0769.70000, 2219.78000
00046 0000.00030, 0018.70000, 0769.70000, 2219.78000
00047 0000.00040, 0018.70000, 0769.70000, 2219.78000
00048 0000.00050, 0018.70000, 0769.70000, 2219.78000
00049 0000.00060, 0021.85000, 0760.60000, 2250.92000
00050 0000.00070, 0021.85000, 0760.60000, 2250.92000
00051 0000.00080, 0021.85000, 0760.60000, 2250.92000
00052 0000.00090, 0021.85000, 0760.60000, 2250.92000
00053 0000.00100, 0021.85000, 0760.60000, 2250.92000
00054 0000.00110, 0021.85000, 0760.60000, 2250.92000
00055 0000.00120, 0021.85000, 0760.60000, 2250.92000
00056 0000.00130, 0021.85000, 0760.60000, 2250.92000
00057 QUIT primary nozzle data input
00058
00059 STOP reading DATA

```

APPENDIX D - OUTPUT LISTING FOR CASE 1

***** TEA INPUT *****

Test for step change in primary flow for STVOL ejector design.

CHECK PRINT LEVEL IS 100

EJECTOR GEOMETRIC CHARACTERISTICS,

| | | | |
|-------|---------|-------|---------|
| X0 = | 9.36000 | Y0 = | 1.25000 |
| X1 = | 0.10801 | Y1 = | 0.10801 |
| NX1 = | 12 | NY1 = | 3 |
| X2 = | 0.78000 | Y2 = | 0.34700 |
| X3 = | 9.36000 | Y3 = | 1.04100 |
| X4 = | 9.36000 | Y4 = | 1.87500 |
| Z1 = | 0.90000 | NZ = | 5 |

MIXING LOSS CORRECTION FACTOR

BETA = 1.05500

KINETIC ENERGY MIXING COEFFICIENT

CSIGMA = 0.30000

FREE-STREAM THERMODYNAMIC PROPERTIES

| | | | |
|---------------------|---|------------|-------------|
| STATIC TEMPERATURE | = | 542.79999 | DEG-RANKINE |
| STATIC PRESSURE | = | 2067.84009 | LB-F/FT3 |
| SPECIFIC HEAT RATIO | = | 1.40000 | |
| GAS CONSTANT, AIR | = | 1714.54126 | FT2/S2-R |
| FREESTREAM VELOCITY | = | 0.00000 | FT/S |
| ANGLE-OF-ATTACK | = | 90.00000 | DEGREES |

EJE BACK PRESSURE IS 2067.84009 LBF/FT2

PRIMARY NOZZLE DATA

| DATA SET# | T (sec) | DMPDT (lbm/s) | T1P0 (degR) | P1P (lbf/ft2) |
|--------------|------------|------------------|----------------|------------------|
| 1 | 0.00040 | 18.70000 | 769.70001 | 2219.78003 |
| 2 | 0.00050 | 18.70000 | 769.70001 | 2219.78003 |
| 3 | 0.00060 | 21.85000 | 760.59998 | 2250.91992 |
| 4 | 0.00070 | 21.85000 | 760.59998 | 2250.91992 |
| 5 | 0.00080 | 21.85000 | 760.59998 | 2250.91992 |

PROGRAM WILL OPERATE ON 5 DATA SETS

APPENDIX D - OUTPUT LISTING FOR CASE 1

***** SINGLE POINT CALCULATION *****

T = 0.00040 sec

FIELD VARIABLE PROFILE:

| Station -> | Infinity | 1P | 1S | 3 | 4 | |
|------------|------------|------------|------------|------------|------------|---------|
| AREA | 11.70000 | 0.41998 | 9.32378 | 9.74376 | 17.55000 | FT |
| V | 0.00000 | 769.94739 | 282.19669 | 304.57248 | 164.99725 | FT/S |
| P | 2067.84009 | 2219.78003 | 1980.71228 | 1997.96570 | 2067.84009 | LBF/FT2 |
| PO | 2067.84009 | 2799.79346 | 2067.84009 | 2097.37158 | 2097.37158 | LBF/FT2 |
| T | 542.79999 | 720.30579 | 536.16473 | 553.28766 | 558.74860 | DEG-R |
| TO | 542.79999 | 769.70001 | 542.79999 | 561.01691 | 561.01691 | DEG-R |
| RHO | 0.07149 | 0.05783 | 0.06932 | 0.06776 | 0.06945 | LBM/FT3 |
| MDOT | 0.00000 | 18.70000 | 182.39970 | 201.09969 | 201.09970 | LBM/S |

NOTES:

Nozzle Pressure Ratio is 1.35397 (Choked NPR is 1.89293)

Station 3-4 SURGE error is 0.00002361

Solution obtained in 17 iterations, limit is 50

FINITE VOLUME PROFILE

| Station | Z | B,inner | B,outer | B,jsl |
|---------|-------------|-------------|-------------|-------------|
| 2 | 0.18000E+00 | 0.12857E-02 | 0.42297E-01 | 0.10382E-01 |
| 3 | 0.36000E+00 | 0.00000E+00 | 0.67784E-01 | 0.16039E-01 |
| 4 | 0.54000E+00 | 0.00000E+00 | 0.93272E-01 | 0.19376E-01 |
| 5 | 0.72000E+00 | 0.00000E+00 | 0.11876E+00 | 0.21867E-01 |
| 6 | 0.90000E+00 | 0.00000E+00 | 0.14425E+00 | 0.23816E-01 |

| Station | Rho | P | Vm | Ve |
|---------|-------------|-------------|-------------|-------------|
| 1 | 0.17974E-02 | 0.22198E+04 | 0.76995E+03 | 0.28220E+03 |
| 2 | 0.20635E-02 | 0.19575E+04 | 0.10653E+04 | 0.27064E+03 |
| 3 | 0.20895E-02 | 0.19822E+04 | 0.73541E+03 | 0.27064E+03 |
| 4 | 0.20987E-02 | 0.19909E+04 | 0.59600E+03 | 0.27064E+03 |
| 5 | 0.21033E-02 | 0.19953E+04 | 0.52124E+03 | 0.27064E+03 |
| 6 | 0.21061E-02 | 0.19980E+04 | 0.47450E+03 | 0.27064E+03 |

| Element | D(Rho)/DT | D(P)/DT | D(Vm)/DT | D(Ve)/DT |
|---------|-------------|-------------|-------------|-------------|
| 1 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 2 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 3 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 4 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |
| 5 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 | 0.00000E+00 |

NOTES:

Inner jet expansion, Theta1 0.08603 radians

Outer jet expansion, Theta2 0.14066 radians

Initial jet width, B0, 0.01681 Ft

Allowable jet width, Bmax, 0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 926.57001 Lb
 Isentropic primary thrust = 508.74969 Lb
 Thrust augmentation ratio = 1.82127

APPENDIX D - OUTPUT LISTING FOR CASE 1

***** SINGLE POINT CALCULATION *****

T = 0.00050 sec

FIELD VARIABLE PROFILE:

| Station -> | Infinity | 1P | 1S | 3 | 4 | |
|------------|------------|------------|------------|------------|------------|---------|
| AREA | 11.70000 | 0.41998 | 9.32378 | 9.74376 | 17.55000 | FT |
| V | 0.00000 | 769.94739 | 282.19650 | 304.57236 | 164.98514 | FT/S |
| P | 2067.84009 | 2219.78003 | 1980.71240 | 1997.96570 | 2067.99219 | LBF/FT2 |
| PO | 2067.84009 | 2799.79346 | 2067.84009 | 2097.37158 | 2097.37158 | LBF/FT2 |
| T | 542.79999 | 720.30579 | 536.16474 | 553.28766 | 558.74890 | DEG-R |
| TO | 542.79999 | 769.70001 | 542.79999 | 561.01691 | 561.01691 | DEG-R |
| RHO | 0.07149 | 0.05783 | 0.06932 | 0.06776 | 0.06945 | LBM/FT3 |
| MDOT | 0.00000 | 18.70000 | 182.39959 | 201.09961 | 201.09961 | LBM/S |

NOTES:

Nozzle Pressure Ratio is 1.35397 (Choked NPR is 1.89293)

FINITE VOLUME PROFILE

| Station | Z | B,inner | B,outer | B,jsl |
|---------|-------------|-------------|-------------|-------------|
| 2 | 0.18000E+00 | 0.12857E-02 | 0.42297E-01 | 0.10382E-01 |
| 3 | 0.36000E+00 | 0.00000E+00 | 0.67784E-01 | 0.16039E-01 |
| 4 | 0.54000E+00 | 0.00000E+00 | 0.93272E-01 | 0.19376E-01 |
| 5 | 0.72000E+00 | 0.00000E+00 | 0.11876E+00 | 0.21867E-01 |
| 6 | 0.90000E+00 | 0.00000E+00 | 0.14425E+00 | 0.23816E-01 |

| Station | Rho | P | Vm | Ve |
|---------|-------------|-------------|-------------|-------------|
| 1 | 0.17974E-02 | 0.22198E+04 | 0.76995E+03 | 0.28220E+03 |
| 2 | 0.20635E-02 | 0.19575E+04 | 0.10653E+04 | 0.27064E+03 |
| 3 | 0.20895E-02 | 0.19822E+04 | 0.73541E+03 | 0.27064E+03 |
| 4 | 0.20987E-02 | 0.19909E+04 | 0.59600E+03 | 0.27064E+03 |
| 5 | 0.21033E-02 | 0.19953E+04 | 0.52124E+03 | 0.27064E+03 |
| 6 | 0.21061E-02 | 0.19980E+04 | 0.47450E+03 | 0.27064E+03 |

| Element | D(Rho)/DT | D(P)/DT | D(Vm)/DT | D(Ve)/DT |
|---------|--------------|--------------|--------------|--------------|
| 1 | 0.00000E+00 | 0.44516E+00 | 0.71454E-02 | -0.18450E+01 |
| 2 | 0.00000E+00 | 0.22258E+00 | 0.61080E-02 | -0.18450E+01 |
| 3 | 0.42453E-06 | 0.44516E+00 | 0.57823E+00 | -0.18450E+01 |
| 4 | -0.42453E-06 | 0.22258E+00 | -0.44430E+00 | -0.18450E+01 |
| 5 | -0.42453E-06 | -0.22258E+00 | -0.37205E+00 | -0.18450E+01 |

NOTES:

Inner jet expansion, Theta1 0.08603 radians

Outer jet expansion, Theta2 0.14066 radians

Initial jet with, B0, 0.01681 Ft

Allowable jet width, Bmax, 0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 926.50159 Lb
 Isentropic primary thrust = 508.74969 Lb
 Thrust augmentation ratio = 1.82113

APPENDIX D - OUTPUT LISTING FOR CASE 1

***** SINGLE POINT CALCULATION *****

T = 0.00060 sec

FIELD VARIABLE PROFILE:

| Station -> | Infinity | 1P | 1S | 3 | 4 | |
|------------|------------|------------|------------|------------|------------|---------|
| AREA | 11.70000 | 0.41998 | 9.32378 | 9.74376 | 17.55000 | FT |
| V | 0.00000 | 860.78772 | 282.19669 | 303.30927 | 164.33514 | FT/S |
| P | 2067.84009 | 2250.91992 | 1980.71228 | 1998.06897 | 2067.49927 | LBF/FT2 |
| PO | 2067.84009 | 3027.15869 | 2067.84009 | 2096.64307 | 2096.64307 | LBF/FT2 |
| T | 542.79999 | 698.86292 | 536.16473 | 553.28772 | 558.70282 | DEG-R |
| TO | 542.79999 | 760.59998 | 542.79999 | 560.95300 | 560.95300 | DEG-R |
| RHO | 0.07149 | 0.06044 | 0.06932 | 0.06777 | 0.06944 | LBM/FT3 |
| MDOT | 0.00000 | 21.85001 | 182.39970 | 200.27596 | 200.27597 | LBM/S |

NOTES:

Nozzle Pressure Ratio is 1.46392 (Choked NPR is 1.89293)

FINITE VOLUME PROFILE

| Station | Z | B,inner | B,outer | B,jsl |
|---------|-------------|-------------|-------------|-------------|
| 2 | 0.18000E+00 | 0.46881E-04 | 0.41181E-01 | 0.11199E-01 |
| 3 | 0.36000E+00 | 0.00000E+00 | 0.65551E-01 | 0.15560E-01 |
| 4 | 0.54000E+00 | 0.00000E+00 | 0.89922E-01 | 0.18624E-01 |
| 5 | 0.72000E+00 | 0.00000E+00 | 0.11429E+00 | 0.20934E-01 |
| 6 | 0.90000E+00 | 0.00000E+00 | 0.13866E+00 | 0.22756E-01 |

| Station | Rho | P | Vm | Ve |
|---------|-------------|-------------|-------------|-------------|
| 1 | 0.18785E-02 | 0.22509E+04 | 0.86079E+03 | 0.28220E+03 |
| 2 | 0.20719E-02 | 0.19656E+04 | 0.10916E+04 | 0.27064E+03 |
| 3 | 0.20910E-02 | 0.19836E+04 | 0.73827E+03 | 0.27068E+03 |
| 4 | 0.20992E-02 | 0.19914E+04 | 0.59681E+03 | 0.27068E+03 |
| 5 | 0.21036E-02 | 0.19955E+04 | 0.52150E+03 | 0.27068E+03 |
| 6 | 0.21063E-02 | 0.19981E+04 | 0.47460E+03 | 0.27068E+03 |

| Element | D(Rho)/DT | D(P)/DT | D(Vm)/DT | D(Ve)/DT |
|---------|-------------|-------------|-------------|-------------|
| 1 | 0.83474E-01 | 0.80936E+05 | 0.26340E+06 | 0.18311E+01 |
| 2 | 0.14618E-01 | 0.14168E+05 | 0.28578E+05 | 0.18311E+01 |
| 3 | 0.57034E-02 | 0.54621E+04 | 0.80213E+04 | 0.18311E+01 |
| 4 | 0.23664E-02 | 0.22534E+04 | 0.26043E+04 | 0.18311E+01 |
| 5 | 0.10866E-02 | 0.10325E+04 | 0.98203E+03 | 0.18311E+01 |

NOTES:

Inner jet expansion, Theta1 0.09286 radians

Outer jet expansion, Theta2 0.13457 radians

Initial jet with, B0, 0.01681 Ft

Allowable jet width, Bmax, 0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 919.07166 Lb
 Isentropic primary thrust = 659.06592 Lb
 Thrust augmentation ratio = 1.39451

APPENDIX D - OUTPUT LISTING FOR CASE 1

***** SINGLE POINT CALCULATION *****

T = 0.00070 sec

FIELD VARIABLE PROFILE:

| Station -> | Infinity | 1P | 1S | 3 | 4 | |
|------------|------------|------------|------------|------------|------------|---------|
| AREA | 11.70000 | 0.41998 | 9.32378 | 9.74376 | 17.55000 | FT |
| V | 0.00000 | 860.78772 | 280.10501 | 301.62244 | 163.46561 | FT/S |
| P | 2067.84009 | 2250.91992 | 1981.97961 | 1998.23413 | 2066.87256 | LBF/FT2 |
| P0 | 2067.84009 | 3027.15869 | 2067.84009 | 2095.70337 | 2095.70337 | LBF/FT2 |
| T | 542.79999 | 698.86292 | 536.26273 | 553.28790 | 558.64166 | DEG-R |
| TO | 542.79999 | 760.59998 | 542.79999 | 560.86810 | 560.86810 | DEG-R |
| RHO | 0.07149 | 0.06044 | 0.06936 | 0.06777 | 0.06943 | LBM/FT3 |
| MDOT | 0.00000 | 21.85001 | 181.13047 | 199.17854 | 199.17854 | LBM/S |

NOTES:

Nozzle Pressure Ratio is 1.46392 (Choked NPR is 1.89293)

FINITE VOLUME PROFILE

| Station | Z | B,inner | B,outer | B,jsl |
|---------|-------------|-------------|-------------|-------------|
| 2 | 0.18000E+00 | 0.00000E+00 | 0.41214E-01 | 0.11696E-01 |
| 3 | 0.36000E+00 | 0.00000E+00 | 0.65618E-01 | 0.15927E-01 |
| 4 | 0.54000E+00 | 0.00000E+00 | 0.90023E-01 | 0.18886E-01 |
| 5 | 0.72000E+00 | 0.00000E+00 | 0.11443E+00 | 0.21151E-01 |
| 6 | 0.90000E+00 | 0.00000E+00 | 0.13883E+00 | 0.22978E-01 |

| Station | Rho | P | Vm | Ve |
|---------|-------------|-------------|-------------|-------------|
| 1 | 0.18785E-02 | 0.22509E+04 | 0.86079E+03 | 0.28011E+03 |
| 2 | 0.20775E-02 | 0.19712E+04 | 0.11092E+04 | 0.26850E+03 |
| 3 | 0.20937E-02 | 0.19863E+04 | 0.74354E+03 | 0.26858E+03 |
| 4 | 0.21005E-02 | 0.19926E+04 | 0.59852E+03 | 0.26859E+03 |
| 5 | 0.21041E-02 | 0.19960E+04 | 0.52205E+03 | 0.26860E+03 |
| 6 | 0.21064E-02 | 0.19982E+04 | 0.47475E+03 | 0.26860E+03 |

| Element | D(Rho)/DT | D(P)/DT | D(Vm)/DT | D(Ve)/DT |
|---------|-------------|-------------|-------------|--------------|
| 1 | 0.56055E-01 | 0.55826E+05 | 0.17555E+06 | -0.20917E+05 |
| 2 | 0.27180E-01 | 0.26487E+05 | 0.52730E+05 | -0.20917E+05 |
| 3 | 0.12250E-01 | 0.11782E+05 | 0.17126E+05 | -0.20917E+05 |
| 4 | 0.50163E-02 | 0.47934E+04 | 0.54920E+04 | -0.20917E+05 |
| 5 | 0.17346E-02 | 0.16524E+04 | 0.15618E+04 | -0.20917E+05 |

NOTES:

Inner jet expansion, Theta1 0.09330 radians

Outer jet expansion, Theta2 0.13476 radians

Initial jet with, B0, 0.01681 Ft

Allowable jet width, Bmax, 0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 909.19916 Lb
 Isentropic primary thrust = 659.06592 Lb
 Thrust augmentation ratio = 1.37953

APPENDIX D - OUTPUT LISTING FOR CASE 1

***** SINGLE POINT CALCULATION *****
T = 0.00080 sec

FIELD VARIABLE PROFILE:

| Station -> | Infinity | 1P | 1S | 3 | 4 | |
|------------|------------|------------|------------|------------|------------|---------|
| AREA | 11.70000 | 0.41998 | 9.32378 | 9.74376 | 17.55000 | FT |
| V | 0.00000 | 860.78772 | 282.21085 | 303.42273 | 164.39374 | FT/S |
| P | 2067.84009 | 2250.91992 | 1980.70361 | 1998.74744 | 2068.25391 | LBF/FT2 |
| PO | 2067.84009 | 3027.15869 | 2067.84009 | 2097.42896 | 2097.42896 | LBF/FT2 |
| T | 542.79999 | 698.86292 | 536.16406 | 553.28845 | 558.70764 | DEG-R |
| TO | 542.79999 | 760.59998 | 542.79999 | 560.95941 | 560.95941 | DEG-R |
| RHO | 0.07149 | 0.06044 | 0.06932 | 0.06779 | 0.06947 | LBM/FT3 |
| MDOT | 0.00000 | 21.85001 | 182.40828 | 200.41866 | 200.41867 | LBM/S |

NOTES:

Nozzle Pressure Ratio is 1.46392 (Choked NPR is 1.89293)

FINITE VOLUME PROFILE

| Station | Z | B,inner | B,outer | B,jsl |
|---------|-------------|-------------|-------------|-------------|
| 2 | 0.18000E+00 | 0.47418E-04 | 0.41180E-01 | 0.11992E-01 |
| 3 | 0.36000E+00 | 0.00000E+00 | 0.65550E-01 | 0.16289E-01 |
| 4 | 0.54000E+00 | 0.00000E+00 | 0.89920E-01 | 0.19109E-01 |
| 5 | 0.72000E+00 | 0.00000E+00 | 0.11429E+00 | 0.21208E-01 |
| 6 | 0.90000E+00 | 0.00000E+00 | 0.13866E+00 | 0.22894E-01 |

| Station | Rho | P | Vm | Ve |
|---------|-------------|-------------|-------------|-------------|
| 1 | 0.18785E-02 | 0.22509E+04 | 0.86079E+03 | 0.28221E+03 |
| 2 | 0.20811E-02 | 0.19748E+04 | 0.11206E+04 | 0.27057E+03 |
| 3 | 0.20969E-02 | 0.19894E+04 | 0.74972E+03 | 0.27066E+03 |
| 4 | 0.21024E-02 | 0.19945E+04 | 0.60126E+03 | 0.27069E+03 |
| 5 | 0.21051E-02 | 0.19970E+04 | 0.52321E+03 | 0.27069E+03 |
| 6 | 0.21070E-02 | 0.19987E+04 | 0.47524E+03 | 0.27070E+03 |

| Element | D(Rho)/DT | D(P)/DT | D(Vm)/DT | D(Ve)/DT |
|---------|-------------|-------------|-------------|-------------|
| 1 | 0.36388E-01 | 0.35501E+05 | 0.11427E+06 | 0.21058E+05 |
| 2 | 0.31656E-01 | 0.30789E+05 | 0.61846E+05 | 0.21058E+05 |
| 3 | 0.19465E-01 | 0.18730E+05 | 0.27408E+05 | 0.21058E+05 |
| 4 | 0.10562E-01 | 0.10093E+05 | 0.11643E+05 | 0.21058E+05 |
| 5 | 0.53912E-02 | 0.51329E+04 | 0.48831E+04 | 0.21058E+05 |

NOTES:

Inner jet expansion, Theta1 0.09286 radians
Outer jet expansion, Theta2 0.13457 radians
Initial jet with, B0, 0.01681 Ft
Allowable jet width, Bmax, 0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 920.05444 Lb
Isentropic primary thrust = 659.06592 Lb
Thrust augmentation ratio = 1.39600

APPENDIX D - OUTPUT LISTING FOR CASE 1

***** SOLUTION PROFILE *****

| T (m-sec) | DmpDT (lbm/s) | THRUST (lb) | PHI |
|--------------|------------------|----------------|---------|
| 0.40000 | 18.70000 | 926.57001 | 1.82127 |
| 0.50000 | 18.70000 | 926.50159 | 1.82113 |
| 0.60000 | 21.85001 | 919.07166 | 1.39451 |
| 0.70000 | 21.85001 | 909.19916 | 1.37953 |
| 0.80000 | 21.85001 | 920.05444 | 1.39600 |

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4. Drummond, C.K., and Barankiewicz, W.S.: A Modeling Technique for STOVL Ejector and Volume Dynamics. NASA TM-103167, 1990.
5. Drummond, C.K., and Ouzts, P.J.: Real-Time Simulation of an F110/STOVL Turbofan Engine. NASA TM-102409, 1989.

TABLE I. - EJECTOR GEOMETRY FOR STOVL TEST CASE
[Configuration for 12 nozzles; 112-in. wide duct; 3 orifices per nozzle.]

| Station | Direction | | | |
|-----------------------------------|-------------------------------|-----------------|-------|---------------|
| | X | Y | Z | |
| | Characteristic dimension, ft. | | | |
| 0 | 9.333 | 1.875 | 0.900 | |
| 1 | .108 | .108 | .900 | |
| 2 | .778 | .347 | - | |
| 3 | 9.333 | 1.042 | 2.917 | |
| 4 | 9.333 | 1.875 | - | |
| Mixing region | | | | |
| Volume, dV | Area, dA | Scale factors | | |
| | | Number of Units | | For dV and dA |
| | | n_x | n_y | $N = n_x n_y$ |
| $W dx dz = z_1$ $W dx = z_1 A$ | Wdx | 12 | 3 | 36 |

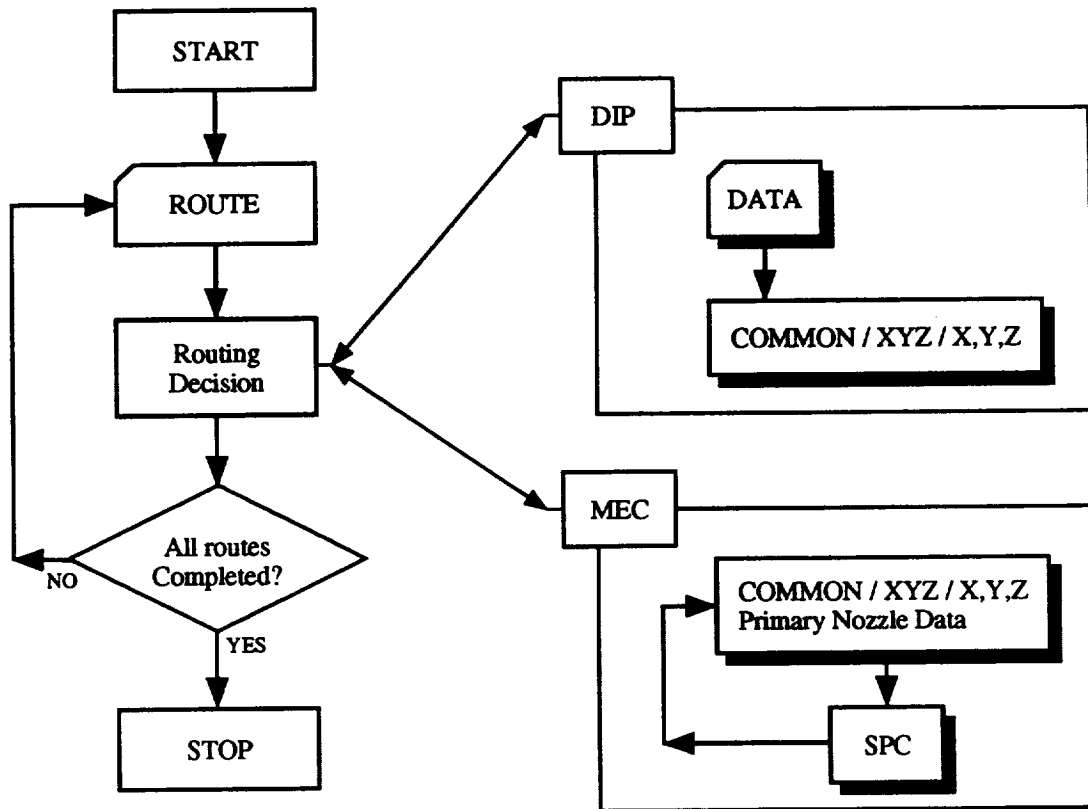


Figure 1. - General program structure.

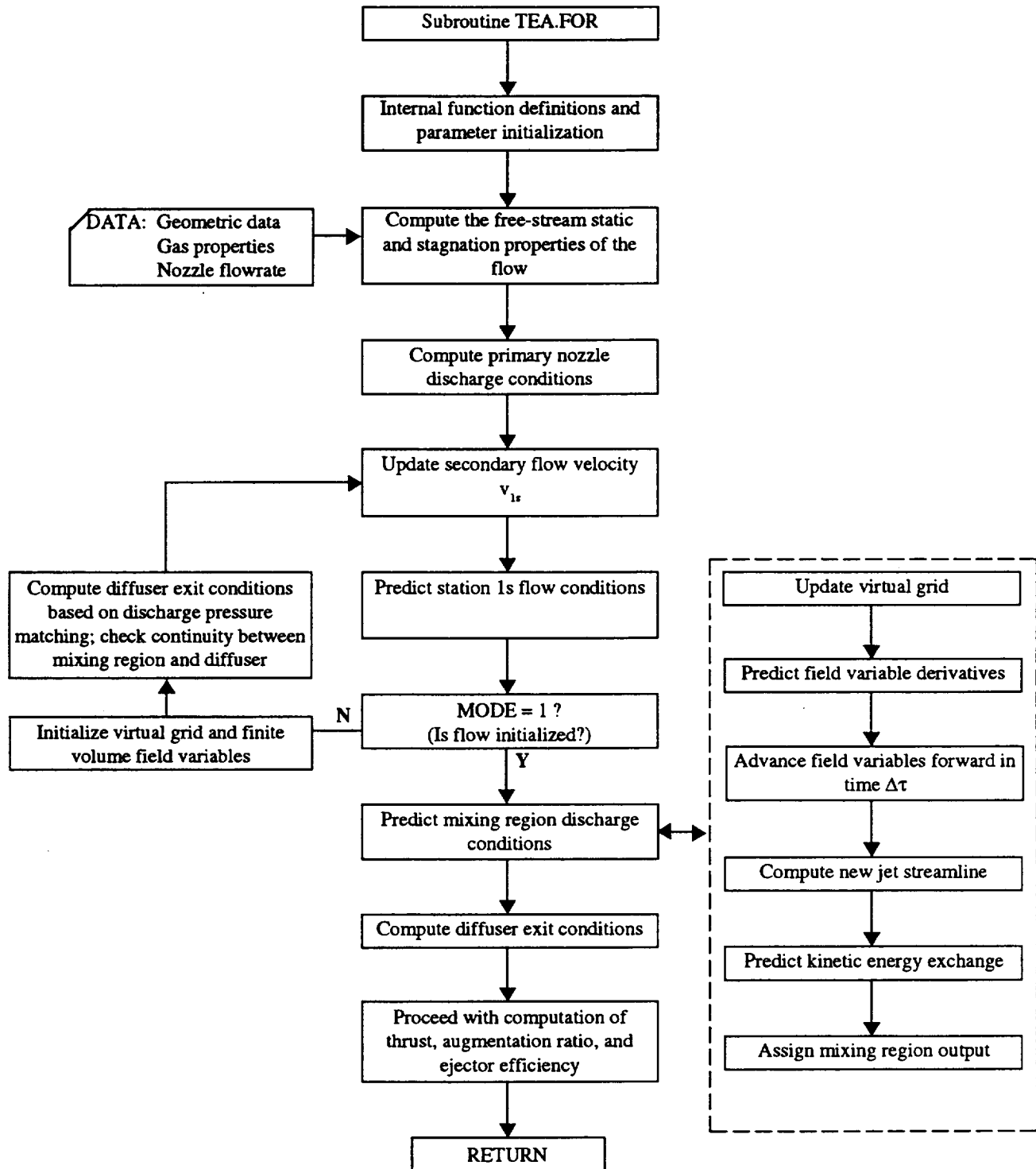


Figure 2 - Outline of the SPC solution procedure.

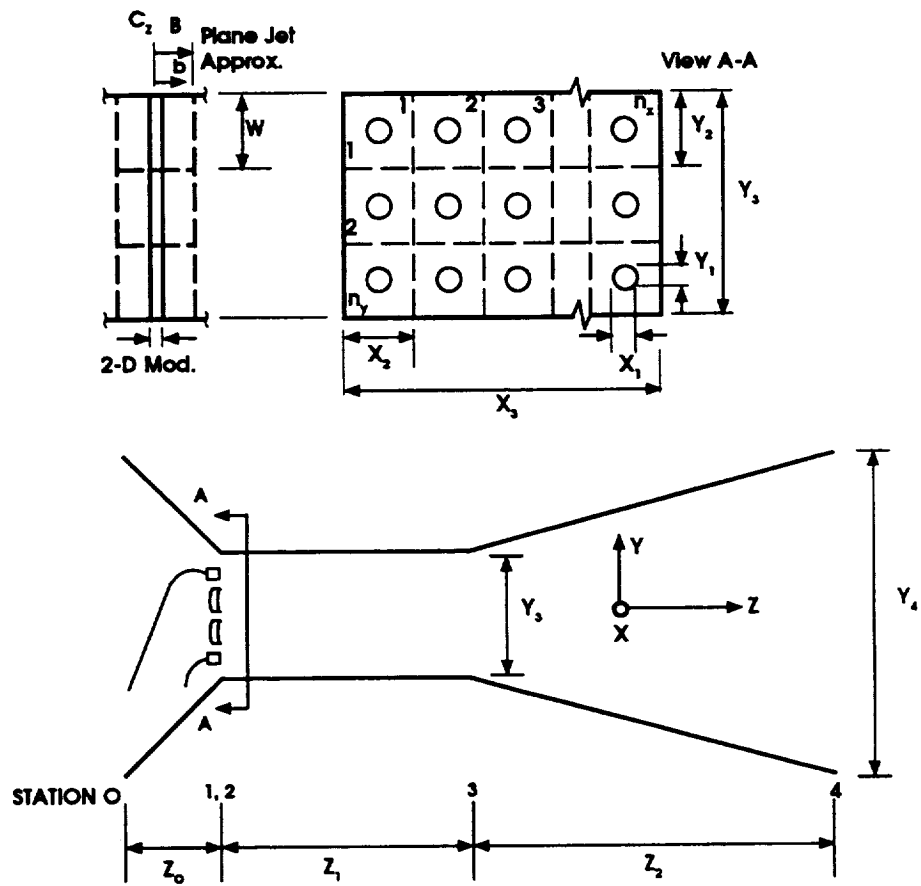


Figure 3. - Geometric ejector approximation.

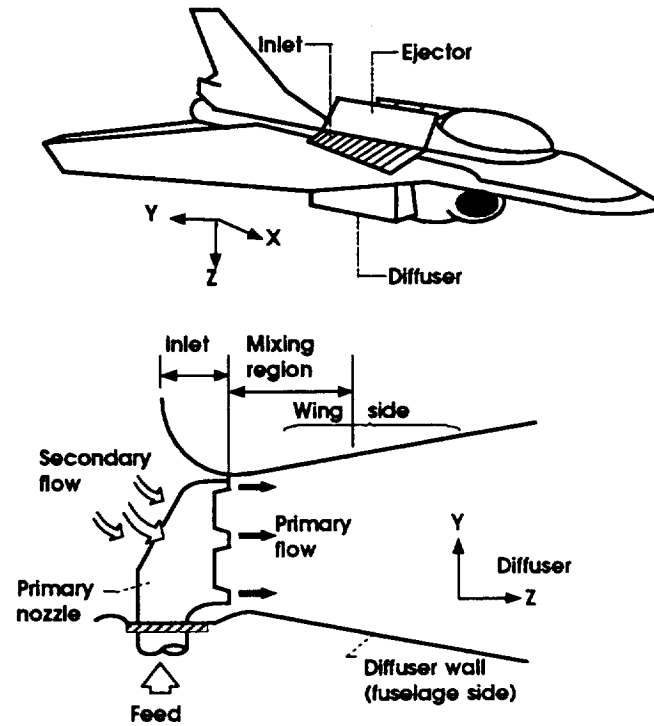


Figure 4. - STOVL ejector application.

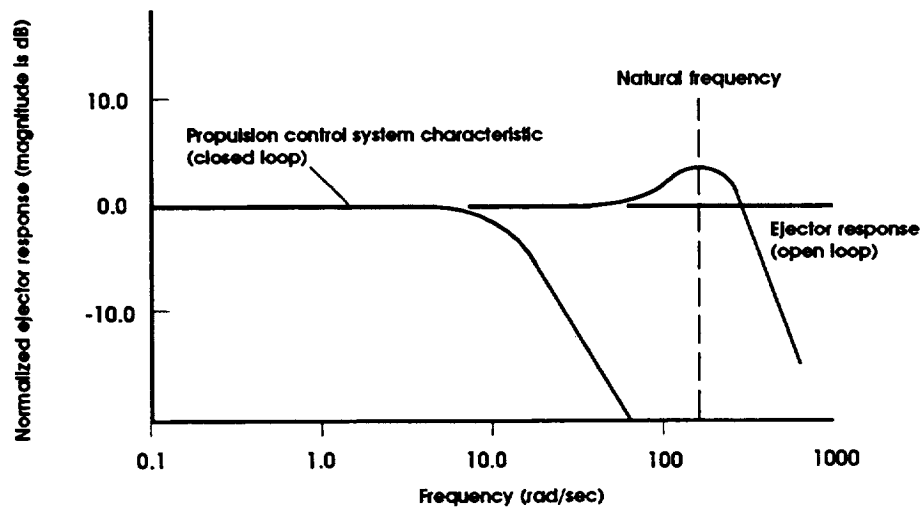


Figure 5. - Quasi-steady response criteria.

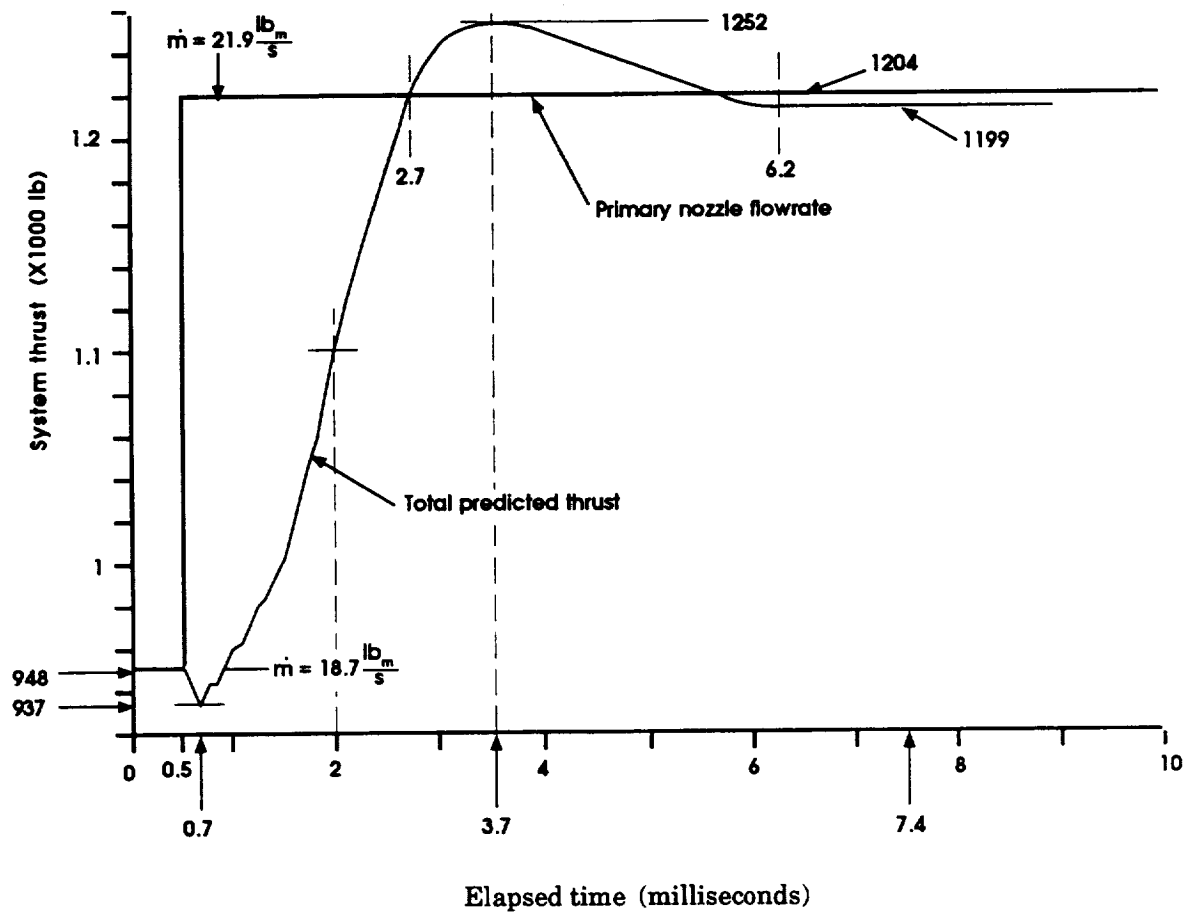


Figure 6. - Result from transient flow test case.

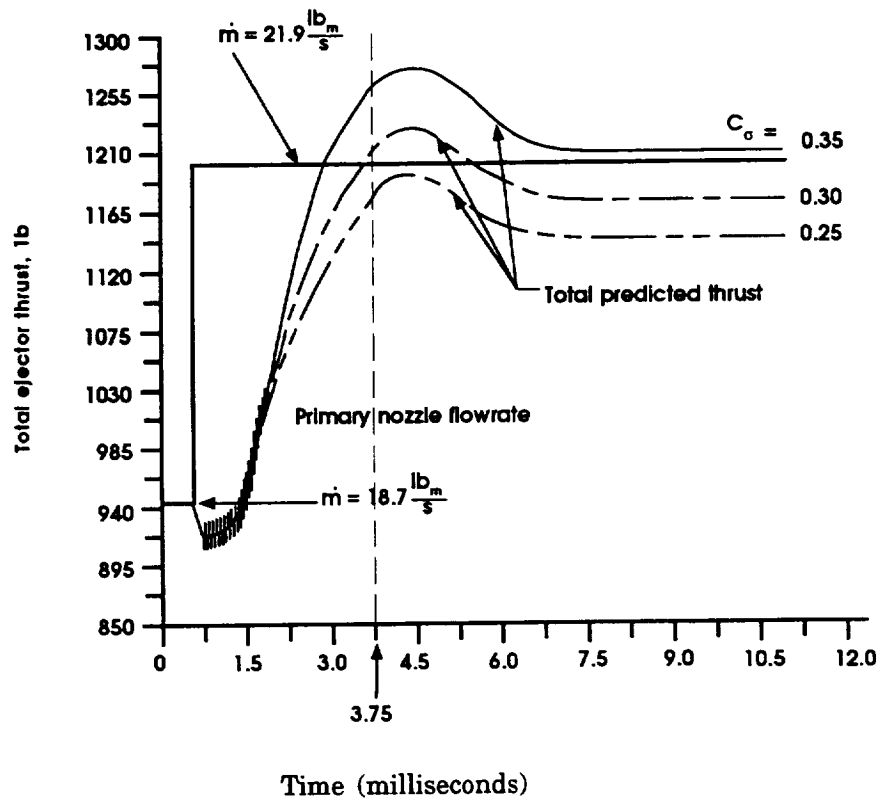


Figure 7. - Effects of CSIGMA on thrust prediction.

| REPORT DOCUMENTATION PAGE | | | Form Approved OMB No. 0704-0188 | |
|---|---|--|---|--|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503. | | | | |
| 1. AGENCY USE ONLY (Leave blank) | | 2. REPORT DATE December 1993 | | 3. REPORT TYPE AND DATES COVERED Technical Memorandum |
| 4. TITLE AND SUBTITLE Transient Ejector Analysis (TEA) Code User's Guide | | | 5. FUNDING NUMBERS WU-505-62-30 | |
| 6. AUTHOR(S) Colin K. Drummond | | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER E-8050 | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, D.C. 20546-0001 | | | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-106310 | |
| 11. SUPPLEMENTARY NOTES Responsible person, Colin K. Drummond, (216) 433-3956. | | | | |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 07 | | | 12b. DISTRIBUTION CODE | |
| 13. ABSTRACT (Maximum 200 words) A FORTRAN computer program for the semianalytic prediction of unsteady thrust augmenting ejector performance has been developed, based on a theoretical analysis for ejectors. That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region. In particular, the inlet and diffuser analyses are simplified by a quasi-steady-analysis, justified by the assumption that pressure is the forcing function in those regions. Only the mixing region is assumed to be dominated by viscous effects. The present work provides an overview of the code structure, a description of the required input and output data file formats, and the results for a test case. Since there are limitations to the code for applications outside the bounds of the test case, the user should consider TEA as a research code (not as a production code), designed specifically as an implementation of the proposed ejector theory. Program error flags are discussed, and some diagnostic routines are presented. | | | | |
| 14. SUBJECT TERMS Ejector; STOV; Control-volume; Transient flow | | | 15. NUMBER OF PAGES 50 | |
| | | | 16. PRICE CODE A03 | |
| 17. SECURITY CLASSIFICATION OF REPORT Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified | 20. LIMITATION OF ABSTRACT | |